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Contents

Foreword

A variety of papers related to highway safety research are presented in this Record. To provide some structure to the Record it is organized in two parts: Part 1 deals with accident studies related to roadway, traffic, and truck characteristics; Part 2 includes reports of research on enforcement, emergency medical services (EMS), safety management, and simulation.

In Part 1, Agent and Pigman quantify the extent of crashes involving vehicles on the shoulders of limited-access highways. In their second paper Pigman and Agent analyze statewide accidents in which "road under construction" is a contributing factor. They also examine 3-year crash data and traffic control devices at 20 case study locations. The safety of one- and two-way streets in Jerusalem from 1983 through 1985 is compared by Hocherman et al. McCoy et al. examine the effect of parking versus no parking and type of parking on state routes. Balbissi reviews work in Jordan to determine the nature and extent of accidents there. Special emphasis is given to the effects of road users and road geometrics on roadway accidents. Concluding Part 1, Lee-Gosselin et al. report on a study that used case-control methodology to predict the change in accident involvement of heavy trucks resulting from mandatory use of tractor front-axle brakes.

Part 2 begins with two papers on enforcement. Freedman et al. present one of the first papers to emerge in the United States on public response to the use of photo radar for automated speed enforcement. Jones analyzes in-depth public attitudes toward traffic regulation, compliance, and enforcement in urban areas in the United Kingdom.

Part 2 continues with a discussion of software developed by Lubkin et al. for local enforcement and engineering agencies to use in building accident report data bases.

Brown et al. present an upgraded optimization technique for allocating highway safety funds. The technique allows for maximum benefits in terms of estimated savings of lives, injuries, and property damage.

Brodsky, using a matched data set from Missouri, shows the impact of communication delay on the response time of emergency medical service.

Concluding Part 2 are two papers on simulation. Heydinger et al. present a methodology for validating computer simulations of physical systems and apply the methodology to vehicle stability and control simulations. Finally, low-cost personal desktop computers and bus-compatible expansion cards are used by Allen et al. for low-cost, part-task driving simulation. An application of the simulation to long-haul truck driver fatigue is discussed.

PART 1

Accident Studies Related to Roadway, Traffic, and Truck Characteristics

Accidents Involving Vehicles Parked on Shoulders of Limited-Access Highways

KENNETH R. AGENT AND JERRY G. PIGMAN

The extent of the problem of accidents involving vehicles on shoulders of limited-access highways was quantified. Accident data for a 3-year period, 1985 through 1987, were collected along with a survey of vehicles stopped on the shoulder on Interstates and parkways. Although the percentage of all accidents on Interstates and parkways involving a vehicle on the shoulder is small (1.8 percent), the percentage of fatal accidents involving a vehicle on the shoulder is significant (11.1 percent). The accident data revealed that the majority of shoulder vehicles had stopped for an emergency stop, as opposed to a leisure stop, with a large number involving an abandoned vehicle; the most common reason for stopping was mechanical failure; tractor-trailers were overrepresented in shoulder accidents; an unusually high percentage occurred in the time period of midnight to 6 a.m. The major contributing factors were alcohol involvement and the driver on the mainline falling asleep. Two types of observational surveys were taken. One survey represented what a driver would observe while driving from one point to another on an Interstate or parkway. This survey indicated that a driver would pass (in his direction of travel) an average of about one vehicle on the shoulder every 8 mi on an Interstate and every 17 mi on a parkway. The second survey was conducted in a circular route so that almost all stops would be observed. The highest percentage of stops were over 1 hr in length.

Stopping or parking on the shoulder of a highway, with the associated hazard of entering and leaving the traveled lanes, has been recognized as a cause of traffic accidents. This study was conducted to quantify the extent of the problem of accidents involving vehicles on shoulders of limited-access highways. Accident data were collected along with a survey of vehicles stopped on the shoulder on Interstates and parkways. The objectives of the study were to

1. Determine if an accident problem existed involving vehicles on the shoulder of the road,
2. Identify locations having the highest frequency of parked vehicles and accidents involving these vehicles,
3. Survey the number of vehicles using the shoulder, and
4. Make recommendations to reduce the frequency of usage and the number of accidents involving vehicles parked on shoulders.

PROCEDURE

Data were collected from two areas. One involved the assemblage of accident data, which were collected for a 3-year period (1985 through 1987) on all Interstates and parkways in Kentucky. This survey included a total of about 735 mi of Interstates and 566 mi of parkways. Accident records were manually searched to obtain related accidents. An accident was included if it involved a vehicle stopped on the shoulder, a vehicle entering or exiting the shoulder, an occupant from a vehicle stopped on the shoulder, a vehicle moving on the shoulder, or if the accident was caused by a vehicle on the shoulder even though that vehicle was not actually involved.

The second area involved an observational survey of vehicles stopped on the shoulders of Interstates and parkways. Vehicles entering or exiting the shoulder were also included. The surveys were conducted while driving; therefore, no direct contact was made with the drivers of the stopped vehicles. For each vehicle observed, information was collected concerning its location, direction, vehicle type, and an opinion regarding the reason for the vehicle using the shoulder. Most of the surveys were conducted to record the number of vehicles on the shoulder that would be encountered while traveling from one point to another on an Interstate or parkway. This type of survey would not result in observing most vehicles that stopped for only a short period. A second type of survey was conducted by driving a short circular route so that most stopped vehicles could be recorded.

RESULTS

Accidents

The number of accidents, obtained from accident records, involving a vehicle on the shoulder are presented in Table 1. A manual search of all accidents occurring on Interstates and parkways was conducted for the 3-year period 1985 through 1987. A total of 424 accidents was located. This total represents 1.8 percent of all accidents on Interstates and parkways. The majority of the accidents (389 accidents) were on Interstates. There are more miles of Interstate highways (about 735 mi) than parkways (about 566 mi) in Kentucky. Also, the traffic volume is higher on Interstates compared with parkways. The percentage of all accidents involving a vehicle on the shoulder was similar for Interstates and parkways (1.8 and 1.6 percent, respectively). The accident rate for accidents involving a vehicle both on Interstate and on parkway shoulders was 1.9 accidents per 100 million vehicle-mi (acc/100 mvm). The rate was substantially higher on Interstates, 2.0 acc/100 mvm, compared with parkways, 1.3 acc/100 mvm.

The majority of accidents (71 percent) involved a vehicle actually stopped on the shoulder. The next most common accident involved a vehicle pulling from the shoulder back onto the main roadway (14 percent). The third most common accident was a secondary accident in which a vehicle on the

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TABLE 1 NUMBER OF ACCIDENTS INVOLVING A VEHICLE ON THE SHOULDER (INTERSTATES AND PARKWAYS)

TYPE OF ACCIDENT	1985	1986	1987	TOTAL
Vehicle Stopped on Shoulder	112	91	97	300
Vehicle Pulling from Shoulder	21	20	17	58
Vehicle Pulling onto Shoulder	9	3	5	17
Motorist Outside Vehicle	4	3	7	14
Secondary Accident	8	9	7	24
Vehicle Moving on Shoulder	8	0	3	11
All	162	126	136	424

shoulder was not actually involved (5.7 percent). This type of accident would occur when a vehicle would pull from the shoulder and a vehicle on the mainline would make an evasive maneuver to avoid the shoulder vehicle, causing an accident. Smaller numbers of accidents were noted for vehicles pulling onto the shoulder (4.0 percent), a motorist outside the vehicle (3.3 percent), and a vehicle moving on the shoulder (2.6 percent). There was no general upward or downward trend in shoulder-type accidents over the 3-year study period, although the largest number occurred in 1985.

The severity of accidents involving a vehicle on the shoulder is presented in Table 2. Of the 424 accidents, 22 involved a fatality, 155 involved injuries, and 247 were property damage only. The 22 accidents involving a fatality represent 11.1 percent of all fatal accidents on Interstates and parkways during the 3-year period, while the 155 injury accidents represent 2.8 percent of all injury accidents. A total of 26 fatalities and 296 injuries resulted from these accidents. Of the 296 injuries, 100 were classified as incapacitating, 112 were classified as nonincapacitating, and 84 were classified as a possible injury. The most severe accident type was the pedestrian accident involving a motorist outside a stopped vehicle. The second most severe accident type involved a vehicle stopped on the shoulder.

Most of the injuries occurred to occupants of the mainline vehicle. Of the 26 fatalities, 20 involved an occupant of the mainline vehicle. Also, 84 percent of the incapacitating injuries and 68 percent of all injuries were associated with the mainline vehicle.

The narrative description and accident diagram given in the police reports were reviewed to determine the reason for stopping on the shoulder. As presented in Table 3, the reason for stopping was determined for about 63 percent of the accidents. When the broad categories presented in Table 3 were considered, the reason for most stops (using the accident data base) involved what was classified as an emergency situation. A much smaller percentage involved what was classified as a leisure activity, while an even smaller percentage involved a work vehicle.

A more detailed explanation for stopping is presented in Table 4. The most common explanation was mechanical failure. A large number of abandoned vehicles would also fall into this category. Other common emergency explanations for stopping were

- Stopping for or being involved in another accident,
- Police vehicle stopping a vehicle,
- Tire problem,
- Bad weather such as heavy rain, and
- Assisting another driver.

The most frequently mentioned leisure explanations were resting, sleeping, changing drivers, and looking at a map. There were instances in which the probable reason for stopping would have been related to leisure but a sufficient explanation was not given. For example, a number of accidents involved a tractor-trailer stopped near the end of an on-ramp. In many instances, this stopping is done when the driver rests, but it could not be classified as a leisure stop unless sufficient information was available.

Various characteristics of the accidents involving a vehicle on the shoulder were summarized and compared to all statewide accidents (see Table 5). When the type of vehicle involved in the accident was considered, the percentage of tractor-

TABLE 2 SEVERITY OF ACCIDENTS INVOLVING A VEHICLE ON THE SHOULDER (INTERSTATES AND PARKWAYS, 1985–1987)

	SEVERITY			
TYPE OF ACCIDENT	FATAL	INJURY	PDO*	TOTAL
Vehicle Stopped on Shoulder	18	111	171	300
Vehicle Pulling From Shoulder	1	21	36	58
Vehicle Pulling onto Shoulder	0	5	12	17
Motorist Outside Vehicle	3	11	0	14
Secondary Accident	0	7	17	24
Vehicle Moving on Shoulder	0	0	11	11
ALL	22	155	247	424

*Property-damage-only accident.

TABLE 3 REASON FOR STOPPING (ACCIDENT DATA)

REASON	NUMBER	PERCENT ALL	PERCENT EXCLUDING UNKNOWN
Emergency	224	52.8	83.9
Leisure	34	8.0	12.7
Work	9	2.1	3.4
Unknown	157	37.0	DNA

trailers involved in shoulder accidents was much higher than for all statewide accidents. Considering all accidents, about 2 percent of all vehicles are tractor-trailers. For shoulder accidents, about 25 percent of the vehicles on the shoulder were tractor-trailers as were about 21 percent of the mainline vehicles. The percentage of single-unit trucks involved in shoulder accidents was also somewhat higher than statewide but not to the extent as determined for tractor-trailers. The percentage of tractor-trailers, as the shoulder vehicle, increased during nighttime hours. About 37 percent of the vehicles on the shoulder, in accidents occurring between 9 p.m. and 6 a.m., were tractor-trailers as compared with 25 percent for all hours of the day.

When light condition and time of accident were analyzed, it was determined that a higher percentage of shoulder accidents occurred during darkness, especially during early morning hours, compared to all accidents. About 36 percent occurred during darkness when there was no roadway lighting (compared to about 12 percent statewide). The percentages of shoulder accidents (25 percent) were much higher than for all accidents (about 7 percent) between the hours of midnight and 6:00 a.m. Conversely, the percentages of shoulder accidents were much lower than for all accidents between the hours of noon and 6:00 p.m.

The severity of shoulder accidents was substantially higher than for all accidents. Approximately 5 percent of shoulder accidents involved a fatality with another 36 percent involving an injury.

Contributing factors relating to the driver (as listed on the police report) determined that shoulder accidents had a higher percentage of accidents involving alcohol or drugs and accidents in which a driver fell asleep or lost consciousness compared to all accidents. The most common contributing factors were alcohol involvement and the driver's falling asleep. The alcohol involvement was almost always related to the driver of the mainline vehicle. These factors relate to the high percentage of late-night and early-morning accidents. Vehicular factors typically were not listed as a contributing factor. Slippery surface was listed as an environmental contributing factor more often than for all accidents.

A higher percentage of shoulder accidents was determined to occur under snow and ice conditions compared with all accidents. This increase would explain the high percentage of shoulder accidents that occurred in January and February.

When roadway character was considered, a higher percentage of shoulder accidents occurred on straight sections having a grade compared with all accidents, and a lower percentage on curves and straight and level sections.

TABLE 4 EXPLANATION FOR STOPPING (ACCIDENT DATA)

EXPLANATION	NUMBER
Mechanical Problem	72
Other Accident	34
Abandoned Vehicle	25
Police Vehicle	20
Tire Problem	19
Bad Weather	18
Assist Other Driver	12
Parked at Ramp	12
Work Vehicle	8
Rest	7
Sleeping	6
Pickup Item that Fell from Vehicle	6
Passing in Emergency Lane	5
Changing Drivers	5
Looking at Map	4
Out of Gas	4
Missed Exit	4
Making U-turn	4
Check on Vehicle	4
Restroom	3

TABLE 5 CHARACTERISTICS OF ACCIDENTS INVOLVING A VEHICLE ON THE SHOULDER (INTERSTATES AND PARKWAYS, 1985–1987)

VARIABLE	CATEGORY	NUMBER	PERCENT	PERCENTAGE STATEWIDE (1986)
Type Vehicle on Shoulder	Automobile	273	64.4	93.0
	Single-Unit Truck	25	5.9	3.1
	Tractor Trailer	105	24.8	2.0
	Other	20	4.7	1.9
Type Vehicle on Mainline	Automobile	314	74.1	93.0
	Single-Unit Truck	18	4.2	3.1
	Tractor Trailer	88	20.8	2.0
	Other	45	10.6	1.9
Light Condition	Daylight	204	48.1	70.9
	Dawn	14	3.3	1.2
	Dusk	8	1.9	2.5
	Darkness-Lighted	47	11.1	13.2
	Darkness-Not Lighted	151	35.6	12.1
Time	0:01 am - 3:00 am	60	14.2	4.9
	3:01 am - 6:00 am	48	11.3	2.5
	6:01 am - 9:00 am	69	16.3	10.0
	9:01 am - Noon	47	11.1	14.5
	12:01 pm - 3:00 pm	50	11.8	20.1
	3:01 pm - 6:00 pm	55	13.0	24.8
	6:01 pm - 9:00 pm	50	11.8	13.9
	9:01 pm - Midnight	44	10.4	9.2
Severity	Fatal	22	5.2	0.5
	Injury	155	36.6	22.1
	Property Damage Only	247	58.3	77.4
Human Contributing Factors	Unsafe Speed	42	9.9	7.3
	Fail to Yield ROW	34	8.0	16.7
	Alcohol Involvement	56	13.2	5.7
	Drug Involvement	6	1.4	0.2
	Fell Asleep	46	10.8	1.0
	Lost Consciousness	6	1.4	0.2
Vehicular Contributing Factors	Tire Failure	3	0.7	0.9
	Steering Failure	2	0.5	0.4
Environmental Contributing Factors	Slippery Surface	62	14.6	7.6
	Improperly Parked Vehicle	13	3.1	0.4
Road Surface Condition	Dry	292	68.9	78.0
	Wet	58	13.7	18.8
	Snow-Ice	74	17.5	3.0
Month	January	54	12.7	7.0
	February	46	10.8	7.5
	March	30	7.1	7.6
	April	29	6.8	8.1
	May	34	8.0	8.9
	June	36	8.5	8.4
	July	33	7.8	8.6
	August	32	7.5	8.6
	September	29	6.8	8.0
	October	32	7.5	9.2
	November	33	7.8	8.9
	December	35	8.3	9.2
Roadway Character	Straight-Level	228	54.0	63.7
	Straight-Grade	138	32.5	17.5
	Straight-Hillcrest	11	2.6	2.8
	Curve-Level	20	4.7	7.4
	Curve-Grade	25	5.9	7.6
	Curve-Hillcrest	2	0.5	1.2

TABLE 6 NUMBER OF ACCIDENTS BY HIGHWAY

HIGHWAY	NUMBER OF ACCIDENTS
I 75	137
I 65	79
I 64	77
I 71	34
I 24	21
I 275	19
I 264	17
Western Ky Parkway	10
Pennyrile Parkway	9
Bluegrass Parkway	5
I 471	3
Green River Parkway	3
Purchase Parkway	3
I 265	2
Cumberland Parkway	2
Daniel Boone Parkway	2
Audubon Parkway	1

The number of shoulder accidents summarized by highway is presented in Table 6. The largest number of accidents was on the longer and higher volume Interstates with I-75 having the highest number followed by I-65 and I-64. Sections of Interstates within certain counties having the highest number of accidents are presented in Table 7. The high volume section of I-75 in northern Kentucky (Kenton and Boone Counties) had the highest number of accidents. Shoulder accidents were also prevalent on other sections of I-75 and on I-65 in counties with heavy traffic volumes.

A list was made of the accidents sorted by route and milepoint. This list was reviewed to determine if locations having high numbers of accidents could be identified. A list of locations having four or more accidents within a 1-mi section is presented in Table 8. Thirteen sections were identified; the shoulder accidents were generally scattered. The section of road having the highest concentration of this type of accident was I-75 from milepoint (MP) 180 to MP 191. This is a high-volume section of Interstate between the US-42 interchange and the Ohio border in northern Kentucky. This section of I-75 had 47 accidents in an 11.6-mi section with an accident rate of 4.5 acc/100 mvm. This rate was substantially higher than the overall rate for shoulder accidents. The locations of rest areas, interchanges, and toll plazas were noted and compared with the location of the accidents. Although there were some accidents, there was no trend or high percentage of accidents at these locations.

The age and sex of the drivers involved in the shoulder accidents were compared to statewide statistics (see Table 9). There was a lower percentage of teenage drivers involved in shoulder accidents, while the percentage of male drivers was higher. The age and sex distribution of the driver of the mainline and the shoulder vehicle was similar for the shoulder accidents.

Surveys of Stopped Vehicles

Three types of analyses were conducted using the data collected for vehicles stopped on the shoulders. For each survey, the date, route, starting time, and ending time were noted. The first type of analysis involved summaries of the number of vehicles stopped per mile as a function of several variables. This analysis used the data collection procedure to represent what a driver would observe while driving from one point to another on an Interstate or parkway.

TABLE 7 HIGHEST NUMBER OF ACCIDENTS BY HIGHWAY AND COUNTY

HIGHWAY	COUNTY	NUMBER OF ACCIDENTS
I 75	Kenton	41
I 75	Boone	19
I 75	Madison	17
I 65	Hardin	16
I 65	Bullitt	14
I 75	Grant	14
I 64	Jefferson	13
I 71	Jefferson	13
I 75	Fayette	12
I 75	Laurel	10
I 65	Warren	11
I 65	Jefferson	10

TABLE 8 LOCATIONS HAVING FOUR OR MORE ACCIDENTS WITHIN A 1-mi SECTION

	MILEPOINT RANGE	NUMBER OF ACCIDENTS
I 65	73.7-74.7	4
	89.2-90.1	4
	94.8-95.2	4
	118.0-119.0	4
	122.0-122.5	5
	132.2-133.2	4
I 75	28.0-28.9	4
	180.0-180.5	5
	181.1-181.7	4
	183.7-184.7	8
	187.5-188.5	7
	188.6-189.4	5
	190.0-190.9	7

The second type of analysis involved summarizing the information collected for each vehicle. The vehicle type and an opinion concerning the reason for stopping on the shoulder were noted for each vehicle. A subjective opinion was given as to whether the reason the vehicle had stopped should be classified in emergency, leisure, or work categories. In some instances, such as a flat tire, the reason for the stop was obvious. However, in many cases, the reason was not obvious and a subjective opinion was given. For example, a vehicle was classified as abandoned if no occupants were observed when driving past the vehicle. If the vehicle had engine problems and was then abandoned, the stop was classified as an emergency. However, if there was no evidence of any problem, the stop was classified as leisure in nature.

The third type of analysis used data collected by driving a short section of an Interstate in a circular route for a period of time.

A summary of the surveys giving the average number of vehicles stopped per mile on the shoulder is presented in Table 10. This summary represents over 8,000 mi of observations, which were made as a vehicle was driven along a section of road (not in a circular path). The data represent what a driver would encounter when driving from one point to another on an Interstate or parkway. Obviously, most vehicles that stopped for only a short period would not be observed unless the stop coincided with the data collection. Therefore, data were not collected on the length of the stop using this procedure. The number of vehicles stopped per mile was higher on Interstates than on parkways. The data show that, on the average, a driver would encounter one shoulder vehicle per 8 mi on an Interstate compared to 17 mi on a parkway (in the vehicle's direction of travel). The difference relates to the higher traffic volumes on Interstates. The number of vehicles stopped per mile was similar for daylight and darkness conditions. When the day of the week was considered, the highest rates were observed for Tuesday, Wednesday, and Thursday. There was not a large variation determined when starting time was considered, but the period of noon to 4 p.m. had the highest rate.

A summary of individual vehicle data from the surveys is presented in Table 11. A total of 1,565 vehicles stopped on shoulders was observed. The largest percentage of vehicles was automobiles (65.1 percent). The next highest percentage was tractor-trailers (22.6 percent) followed by single-unit trucks (11.1 percent). About one-half of the stops were classified as leisure in nature with slightly over one-third classified as emergencies. The remainder of the stops were classified as work-related. This percentage of leisure stops was higher than that determined from the accident data. A reason would be that the narrative contained in the accident report in many instances gave an explanation of the reason for abandoning the vehicle. Typically, a comment was noted related to the vehicle on the shoulder. Almost one-third of all the vehicles observed on the shoulder were abandoned. Most of the work vehicles were

TABLE 9 DRIVER CHARACTERISTICS (ACCIDENT DATA)

VARIABLE	CATEGORY	PERCENT	PERCENTAGE STATEWIDE (1986)
Age	16-19	7.0	15.1
	20-24	14.8	17.9
	25-34	31.7	26.3
	35-44	21.0	16.4
	45-54	11.7	9.4
	55 or above	13.9	14.9
Sex	Male	78.1	62.7
	Female	21.9	37.3

TABLE 10 VEHICLES STOPPED PER MILE

CATEGORY	VARIABLE	LENGTH SURVEYED	VEHICLES STOPPED TOTAL	VEHICLES STOPPED DIRECTION TRAVEL	VEHICLES STOPPED/MILE TOTAL	VEHICLES STOPPED/MILE DIRECTION TRAVEL
Route	I 75	1016.9	212	124	.21	.12
	I 275	13.8	5	3	.36	.22
	I 64	1576.4	272	170	.17	.11
	I 264	88.0	20	14	.23	.16
	I 65	833.0	194	100	.23	.12
	I 265	175.3	47	22	.27	.13
	I 24	279.0	41	26	.15	.09
	I 71	77.0	16	10	.21	.13
	Bluegrass Pkwy	1567.8	186	106	.12	.07
	Western Ky Pkwy	1523.3	171	78	.11	.05
	Mountain Pkwy	477.3	88	39	.18	.06
	Green River Pkwy	139.0	13	9	.09	.06
	Audubon Pkwy	47.0	1	1	.02	.02
	Pennyrile Pkwy	155.0	6	5	.04	.03
	Purchase Pkwy	211.4	22	15	.10	.07
	Daniel Boone Pkwy	57.0	24	5	.42	.09
	Cumberland Pkwy	178.0	21	16	.12	.09
Light Condition	Daylight	6151.3	1030	560	.17	.09
	Darkness	2218.3	307	181	.14	.08
Day	Sunday	747.5	84	45	.11	.06
	Monday	500.1	52	27	.10	.05
	Tuesday	2571.2	471	259	.18	.10
	Wednesday	1747.5	321	170	.18	.10
	Thursday	1496.1	249	150	.17	.10
	Friday	1147.8	141	78	.12	.07
	Saturday	205.0	21	14	.10	.07
Starting Time	Midnight - 4:00 am	775.0	124	64	.16	.08
	4:01 am - 8:00 am	456.5	67	35	.15	.08
	8:01 am - Noon	2896.9	500	272	.17	.09
	Noon - 4:00 pm	2361.3	423	226	.18	.10
	4:01 pm - 8:00 pm	1096.1	129	74	.12	.07
	8:01 pm - Midnight	829.4	96	72	.12	.09
Type Route	Interstate	4059.4	807	469	.20	.12
	Parkway	4355.8	532	274	.12	.06

TABLE 11 SUMMARY OF INDIVIDUAL VEHICLE DATA FROM SURVEY

CATEGORY	VARIABLE	NUMBER	PERCENT
Type of Vehicle	Automobile	1019	65.1
	Single Unit Truck	173	11.1
	Tractor Trailer	353	22.6
	Other	20	1.3
Reason for Stop	Emergency	579	37.0
	Leisure	771	49.3
	Work	215	13.7
Comment Concerning Vehicle	Abandoned	491	31.4
	DOT Vehicle	182	11.6
	Flashers On	138	8.8
	Driver in Vehicle	126	8.1
	Hood Up/Working on Vehicle	125	8.0
	Stopped Past Toll Plaza/ Rest Area	125	8.0
	Person Beside Vehicle	45	2.9
	Police Giving Ticket	32	2.0
	Giving Assistance	28	1.8
	Pulling onto Road	26	1.7
	Flat Tire	23	1.5
	Adjusting Load on Trailer	23	1.5

TABLE 12 TYPE OF VEHICLE VERSUS REASON FOR STOP SURVEYS

	REASON FOR STOP (PERCENT)		
	EMERGENCY	LEISURE	WORK
Automobile	42.3	44.7	13.0
Single Unit Truck	26.0	32.9	41.0
Tractor Trailer	26.3	72.0	1.7

Department of Highways (DOH) vehicles. When the type of vehicle was related to the reason for stopping, it was determined that the percentage of leisure-related stops was much higher for tractor-trailers than automobiles (see Table 12). The percentages of leisure and emergency stops for automobiles were almost identical. When the type of vehicle was related to lighting conditions, the percentage of vehicles on the shoulder classified as tractor-trailers was higher during the nighttime (see Table 13).

Three sections of Interstates were used for the circular route surveys. Data between adjacent interchanges were collected. Two sections were 16 mi in length; one was 14 mi in length. Data were collected during daylight for 2 days and during one nighttime period for each location. A total of about 29 hr of daytime data and 12 hr of nighttime data were collected. Two observers drove separate vehicles in the circular path. Given the short section length and the use of two vehicles, all but a few short stops on the shoulder were observed.

A summary of the locations and times for the circular route surveys along with the number of vehicles observed is presented in Table 14. Using an estimate that approximately one-half the average daily traffic (ADT) would travel during the survey periods, the number of stops per million vehicle miles was calculated. The values ranged from about 260 stops/mvm on I-75 from MP 90 to MP 104, to approximately 320 stops/mvm on I-64 from MP 53 to MP 69, to about 510 stops/mvm on I-75 from MP 120 to MP 136. The high number of stops at one I-75 location was related to trucks stopped near a rest area and a weigh station.

The types of vehicle observed during the circular path surveys is presented in Table 15. As presented previously in Table 11, the highest percentage was for automobiles with a high percentage of tractor-trailer trucks. The percentage of trucks determined from these surveys was higher than that indicated in Table 11. The percentage of tractor-trailer trucks was extremely high at night.

The length of stop observed during the circular route surveys is presented in Table 16. The categories used were under 20 min, 20 to 60 min, and over 60 min. The largest percentage (about one-half of the stops) were over 60 min. These stops would be the emergency stops and the longer leisure stops when the driver would be sleeping.

SUMMARY

Although the percentage of all accidents on Interstates and parkways involving a vehicle on the shoulder is small (1.8 percent), the percentage of fatal accidents involving a vehicle on the shoulder is significant (11.1 percent). The most common type of accident involved a vehicle stopped on the shoulder with the second most common type involving a vehicle pulling from the shoulder. An analysis of the accident data revealed that the large majority of shoulder vehicles had stopped for an emergency stop as opposed to a leisure stop. A large number of the accidents involved a collision with an abandoned vehicle. The most common reason for stopping, as determined by reviewing the accident reports, was related to a mechanical failure. Tractor-trailers were determined to be overrepresented in shoulder accidents when compared with all accidents. About 25 percent of vehicles on the shoulders were tractor-trailers compared with 2 percent of all vehicles involved in an accident. The percentage of shoulder accidents occurring during darkness, in which the highway was not lighted, was much higher for shoulder accidents compared with all accidents. The period of midnight to 6 a.m. had a higher percentage of shoulder accidents compared with all accidents. The severity of shoulder accidents was high when compared with all accidents. The major contributing factors for this type of accident were alcohol involvement and the driver on the mainline falling asleep. Slippery surfaces were also listed in a large percentage of these accidents, especially related to snow and ice conditions.

The largest number of shoulder accidents occurred on I-75, particularly in the high-volume section in northern Kentucky in Kenton County.

An observational survey of shoulder vehicles was conducted representing what a driver would observe while driving from one point to another on an Interstate or parkway. The data included over 8,000 mi of travel, and indicated that a driver

TABLE 13 TYPE OF VEHICLE VERSUS LIGHTING CONDITION SURVEYS

TYPE OF VEHICLE	LIGHTING CONDITION (PERCENT)	
	DAY	NIGHT
Automobile	68.3	55.6
Single Unit Truck	12.0	8.2
Tractor Trailer	18.7	34.1
Other	1.0	2.1

TABLE 14 SUMMARY OF CIRCULAR ROUTE SURVEYS

ROUTE	LENGTH (MILES)	ADT	TIME PERIOD	NUMBER OF VEHICLES STOPPED
Interstate 64 (Milepoint 53-69)	16	20,300	9:50 am - 3:50 pm	21
			11:30 am - 3:30 pm	27
			10:00 pm - 2:00 am	4
Interstate 75 (Milepoint 90-104)	14	30,800	9:05 am - 1:45 pm	24
			11:50 am - 4:00 pm	28
			10:00 pm - 2:00 am	4
Interstate 75 (Milepoint 120-136)	16	23,900	9:50 am - 3:30 pm	41
			12:00 pm - 3:40 pm	31
			10:00 pm - 1:45 am	26

TABLE 15 TYPE OF VEHICLE OBSERVED DURING CIRCULAR ROUTE SURVEYS

VEHICLE TYPE	NUMBER			PERCENT		
	DAY	NIGHT	ALL	DAY	NIGHT	ALL
Automobile	105	5	110	61.0	14.7	53.4
Single Unit Truck	22	0	22	12.8	0.0	10.7
Tractor Trailer	35	28	63	20.3	82.4	30.6
Other	10	1	11	5.8	2.9	5.3

TABLE 16 LENGTH OF STOP OBSERVED DURING CIRCULAR ROUTE SURVEYS

LENGTH OF STOP	NUMBER			PERCENT		
	DAY	NIGHT	ALL	DAY	NIGHT	ALL
Under 20 minutes	35	5	40	20.3	14.7	19.4
20 - 60 minutes	48	18	58	27.9	29.4	28.2
Over 60 minutes	89	19	108	51.9	55.9	52.4

would pass (in his direction of travel) an average of about one vehicle on the shoulder every 8 mi on an Interstate and every 17 mi on a parkway. The number of vehicles encountered was similar during day and night conditions. The most common vehicle noted was an automobile with the percentage of tractor-trailers observed similar to the percentage found in the accident data. The highest percentage of stops was classified as leisure-related (49.3 percent) but the percentage of stops classified as an emergency was not substantially less (37.0 percent). The most frequent comment noted was that the vehicle was abandoned (31.4 percent).

An observational survey was also conducted while traveling in a circular route so that almost all stops would be observed. The highest percentage of stops was over 1 hr in length. These stops were the emergency stops and the longer leisure stops when a driver was sleeping. The percentage of stops by tractor-trailers was high, especially at night.

CONCLUSIONS

Although the number of shoulder-related accidents did not represent a high percentage of accidents on Interstates and parkways, the severity of the accidents (11.1 percent of all fatal accidents) indicates that a problem exists that should be addressed. The types of countermeasures that should be considered include

1. Placement of regulatory signs restricting shoulder parking to emergencies only in areas of high-frequency stops (near rest areas and interchanges),
2. Encouragement of police to investigate every vehicle observed stopped on the shoulder,
3. Encouragement of towing of all abandoned vehicles,
4. Increase in public awareness that abandoned vehicles will be towed if left on the shoulder,
5. Increase in public awareness of the hazards associated with parking a vehicle on the shoulder,
6. Construction of additional rest areas,
7. Installation of motorist emergency telephones, and
8. Provision of a standard design for shoulders, to include a section of indentations near the roadway edge to give an audible warning to drivers that their vehicle is off the roadway.

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Highway Accidents in Construction and Maintenance Work Zones

JERRY G. PIGMAN AND KENNETH R. AGENT

Statewide accidents in which road under construction was listed as a contributing factor were documented for the period 1983 through 1986. Accident data and traffic control devices used at 20 case study locations were analyzed. Accident data at these locations for a 3-year period before construction were compared with accident data for the period during construction. Approximately 500 accidents per year were reported as occurring in work zones for the period 1983 through 1986. In general, work zone accidents are more severe than other accidents. There are high percentages of rear end and sideswipe accidents; following too close is the most frequently listed contributing factor. There is a high percentage of accidents involving trucks. The analysis of 19 case study locations revealed that at 14 sites the accident rates during construction exceeded those before construction. Of the 14 sites, 10 had rates during construction that exceeded statewide averages and six exceeded statewide critical rates. Similar characteristics (types of accidents and contributing factors) were found to exist at the same study locations when compared with statewide work zone accidents. Traffic control at case study sites was generally found to be in conformance with specified standards.

Construction and maintenance work zones have traditionally been hazardous locations within the highway environment. Studies show that accident rates at construction and maintenance work zones are higher than similar periods before the work zones were set up (*1–3*). Factors that have been cited as reasons for the increase in accident rates include (a) inappropriate use of traffic control devices, (b) poor traffic management, (c) inadequate layout of the overall work zone, and (d) a general misunderstanding of the unique problems associated with construction and maintenance work zones.

Proper interpretation of traffic control details and usage of traffic control devices is necessary to alert drivers of impending conditions and hazards and direct them through work zones.

A significant amount of research has been completed in the area of safety associated with construction and maintenance work zones. Proper use of traffic control devices, work activity scheduling, and personnel training have been areas of emphasis in previous studies. Training courses developed and presented by FHWA have addressed many of the problems. In addition, most state highway agencies have devoted considerable attention to their work zone traffic control policies and training of their employees.

Even with the work zone safety problems being addressed, there is still a distinct need for improvement. This need is related to the shift from building new facilities to the improvement of existing facilities. There have also been recent increases in the volumes of traffic and changes in the composition of the traffic stream. On the Interstate system, major reconstruction and resurfacing projects have had to contend with overall increases in volumes of traffic and percentages of trucks. The size, weight, and handling characteristics of trucks require that additional consideration be given to these vehicles in work zones. Large trucks are involved in fewer accidents per mile of travel than passenger cars; however, their involvement rate in fatal accidents is almost twice that of passenger cars (*4,5*).

Training of personnel involved with construction and maintenance work zones has also been given a significant amount of attention. Varying levels of training have been offered and benefits have been realized. Development of traffic control plans is usually the responsibility of the design and traffic engineers. These engineers, along with the resident engineers on the job site, need to be completely familiar with the proper usage of appropriate traffic control devices. The devices are necessary to alert drivers of impending conditions and hazards and direct them through the proper path. Highway agency employees, responsible for traffic control during maintenance operations, and construction company employees, responsible for providing traffic control, are also involved in work zone safety. The efforts of this research were directed at identifying and offering solutions to problems that confront personnel involved with traffic control for construction and maintenance operations.

DATA COLLECTION

Statewide Work Zone Accidents

Accident data were collected from the Kentucky Accident Reporting System (KARS) computer file for the time period of 1983 through 1986. Only those accidents with road under construction listed as an environmental contributing factor were identified and summarized. In addition, copies of the accident reports were obtained for more details about the accident.

Case Study Locations

The objective of this phase of the study was to collect data to document the types of traffic control being used and to follow up with the collection of accident data both in the field and through computer accident records at 20 case study locations. Field inspections were accomplished in the summer construction seasons of 1986 and 1987. Existing traffic control

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was documented by written descriptions and photographs at 18 of the 20 case study locations. The case study locations included projects ranging from construction of a bridge on County Road 5001 in Harrison County to a spot pavement replacement project of over 50 mi of I-75 in Whitley and Laurel counties.

A request was made for the resident engineer on each project to provide accident report forms when an accident occurred in the field; however, few reports were received and it became necessary to rely on centralized computer accident records. Computer searches were made and output was produced during a 3-year period before the work zone was in place and then during the time work was occurring.

Additional traffic control information was obtained from the contract proposal. Bid tabulations for each project were examined and both lump sum and incidental bid items relating to maintaining and controlling traffic were summarized.

ANALYSIS AND RESULTS

Statewide Work Zone Accidents

The total number of statewide accidents in Kentucky for 1983 through 1986 in which road under construction was given as an environmental contributing factor is presented in Table 1. There were some variations over the 4-year period, with an average of about 500 accidents per year. These are the accidents in which the investigating officer listed road construction as a contributing factor and, therefore, would not include all accidents occurring in work zones. In the 4-year period, there were 19 fatalities resulting from 18 fatal accidents and 883 injuries, or about 220 injuries per year. Of the 18 fatal accidents, 8 were single vehicle, 8 were multiple vehicle, and 2 involved pedestrians (1 was a construction worker).

Most accidents (about one-third) occurred on Interstates with the largest number occurring on I-75, which is a high-volume Interstate with a large amount of construction activity. Of the accidents, 14 percent occurred on non-state-maintained streets.

Several characteristics of work zone accidents and total statewide accidents were compared (see Table 2). There was a substantially higher percentage of work zone accidents between June and October compared with statewide accidents. This increase was expected because those months corresponded to the construction season. There was no general trend when time of day was compared. The largest difference was for the 9:00 to 11:59 a.m. time period, which had a higher percentage of work zone accidents. There was a smaller percentage of work zone accidents occurring on the weekend compared with statewide accidents, which was related to less work zone activity on the weekend. Work zone accidents involving injury or fatality were more severe than statewide accidents. The percentage of work zone accidents occurring in rural areas was much higher and the percentage in business and residential areas much lower than for all accidents. The percentage of work zone accidents during wet, snow, or ice roadway conditions was low, which was related to less activity during such conditions. When road character was considered, it was found that a higher percentage of work zone accidents than statewide accidents involved a curve. This shows the importance of providing adequate sight distance. There was a smaller percentage of work zone accidents occurring during nondaylight hours, which again relates to the amount of activity.

A comparison of work zone and all accidents by type of accident is presented in Table 3. A much higher percentage of work zone accidents occurred on a roadway section or midblock and a lower percentage at an intersection compared with all accidents. The most common work zone accident was a rear-end or same-direction sideswipe accident on a roadway section or midblock. There were also higher percentages of single-vehicle ran off the road and collision with a nonfixed object types of accidents.

Contributing factors, as given on the police report, of work zone accidents compared with statewide accidents are presented in Table 4. When human factors were considered, the largest difference was a higher percentage of work zone accidents involving following too close as a contributing factor. The percentage of accidents involving unsafe speed was slightly higher for work zone accidents compared with all accidents. There was a lower percentage of accidents involving alcohol in the work zone accidents. The vehicular factors were similar with slightly lower percentages generally noted for work zone accidents. There were also generally lower percentages for environmental factors (other than road construction) for work zone accidents, especially for the slippery surface factor. Exceptions where the percentage was higher for work zone accidents included debris in roadway, shoulders defective, and holes/deep ruts/bumps.

An attempt was made to classify each accident by type of work zone (see Table 5). The work zone categories were construction, maintenance, and utility. The most common type of work zone involved construction, although it could not be determined in many accidents. Maintenance work zones followed, with only a small percentage of accidents identified

TABLE 1 WORK ZONE ACCIDENTS IN KENTUCKY BY YEAR

YEAR	TOTAL ACCIDENTS	FATALITIES	INJURIES
1983	449	2	214
1984	551	7	257
1985	493	5	185
1986	520	5	227

TABLE 2 COMPARISON OF WORK ZONE AND STATEWIDE ACCIDENTS FOR SEVERAL VARIABLES

VARIABLE	CATEGORY	PERCENT OF TOTAL: WORK ZONE ACCIDENTS	PERCENT OF TOTAL: STATEWIDE ACCIDENTS
Month	January	2.3	8.2
	February	1.8	7.4
	March	4.1	7.4
	April	6.1	7.9
	May	8.9	8.8
	June	12.9	8.2
	July	11.8	8.0
	August	14.0	8.4
	September	11.0	8.1
	October	12.6	8.9
	November	9.4	8.8
	December	5.0	9.8
Time of Day	Midnight - 2:59 am	4.9	5.3
	3:00 am - 5:59 am	3.7	2.6
	6:00 am - 8:59 am	11.1	10.1
	9:00 am - 11:59 am	19.2	14.7
	Noon - 2:59 pm	22.0	20.2
	3:00 pm - 5:59 pm	22.5	24.2
	6:00 pm - 8:59 pm	10.4	13.7
	9:00 pm - 11:59 pm	6.3	9.2
Day of Week	Monday	9.3	10.3
	Tuesday	14.0	14.2
	Wednesday	16.0	13.9
	Thursday	16.2	13.8
	Friday	15.7	14.2
	Saturday	17.1	18.3
	Sunday	11.7	15.2
Severity	Fatal	0.9	0.5
	Injury	27.4	21.7
	Property Damage Only	71.7	77.8
Land Use	Rural	54.9	30.1
	Business	28.8	41.4
	Industrial	1.9	0.9
	Residential	13.3	21.6
	School	0.7	2.2
	Park	0.3	0.4
	Private Property	0.2	3.3
Surface Condition	Dry	84.7	72.8
	Wet	14.1	20.1
	Snow-Ice	0.6	6.8
	Slush	0.2	0.2
	Muddy	0.4	0.1
Road Character	Straight-Level	56.3	62.4
	Straight-Grade	21.8	17.9
	Straight-Hill Crest	2.2	3.0
	Curve-Level	9.9	7.6
	Curve-Grade	8.4	8.0
	Curve-Hill Crest	1.3	1.2
Light Condition	Daylight	76.3	70.4
	Dawn	1.2	1.2
	Dusk	1.8	2.5
	Dark-Lights On	6.5	13.3
	Dark-No Lighting	14.1	12.5

TABLE 3 COMPARISON OF ACCIDENT DESCRIPTION

DIRECTIONAL ANALYSIS	PERCENT OF TOTAL: WORK ZONE ACCIDENTS	PERCENT OF TOTAL: STATEWIDE ACCIDENTS
Intersection		
Angle	8.6	14.0
Rear End	2.0	6.2
Opposing Left Turn	1.2	1.1
Opposite Direction	0.5	0.9
Fixed Object	0.2	1.1
Single Vehicle	0.3	0.1
Pedestrian	0.1	0.2
Vehicle Backing	0.7	0.6
Same Direction Sideswipe	0.9	2.0
Roadway Section or Mid-Block		
Rear End	27.3	10.1
Head-On	1.5	1.4
Same Direction Sideswipe	14.2	4.8
Opposite Direction Sideswipe	3.2	4.5
Entering or Leaving Entrance	2.5	5.7
Pedestrian	0.6	0.9
Fixed Object	5.8	10.4
Collision - Not Fixed Object	5.9	0.8
Single Vehicle - Ran Off Road	9.6	4.7
Overturned in Roadway	0.8	0.8
Bridge Related Accidents	1.1	0.3
Interchange Ramp Accidents	2.2	0.4
Miscellaneous Accidents	0.6	13.4
Parking Lot	0.0	13.3

as occurring in a utility work zone. Most of the construction work zone accidents were on Interstates. The high percentage of accidents in construction work zones, compared with maintenance and utility work zones, related to higher exposure (both in terms of length of work and traffic volume).

The description of each accident was reviewed to determine the work zone-related factor that contributed to the accident. Factors were identified in about three-fourths of the accidents (see Table 6). The most common factor was congestion, which agrees with the previous finding that rear end accidents are the most common type of work zone accidents. Restricted lane width was the second most common factor found. There were several accidents involving either hitting or being hit by construction equipment. Another common factor related to the condition of the pavement surface and involved either a material such as gravel or oil on the roadway, an uneven pavement (including potholes and pavement removal), and a pavement (shoulder) dropoff. There were several accidents related to a flagger or construction worker; the most common involved a communication problem between the driver and flagger. Another common factor involved a vehicle merging too late.

The severity of the accidents associated with each factor presented in Table 6 was related using a severity index (SI). The SI is calculated by dividing the number of equivalent property-damage-only (EPDO) accidents by the total number of accidents. As average accident severity increases, the SI increases. EPDO is equal to 9.5 times the number of fatal or incapacitating injury accidents plus 3.5 times the number of nonincapacitating or possible injury accidents plus the number of no injury accidents. The highest severity involved the water pooling and shoulder dropoff accidents. Accidents involving running off the road in a detour were also severe.

The accident severity of the work zone accidents was related to several variables (see Table 7) using the severity index, the percentage of fatal or serious injury accidents, and the percentage of injury or fatal accidents. When work zone type was considered, the most severe accidents were in construction work zones with the least severe in utility work zones. This effect probably related to the traffic speeds. When location in the work zone was considered, the most severe accidents occurred in the advance warning area. The most severe type of accident involved a pedestrian. Other severe types of accidents were head-on, overturning in the roadway, single-vehicle ran off the road, and fixed object. The most common accident types (rear end and same direction sideswipe) were not as severe. Accidents involving trucks were more severe than those in which a truck was not involved. Accidents during darkness, with no lighting, were more severe than accidents during daylight hours or darkness with roadway lighting. Accidents in rural areas were more severe than those in business or residential areas, which related to traffic speeds.

TABLE 4 COMPARISON OF WORK ZONE AND STATEWIDE ACCIDENTS BY CONTRIBUTING FACTOR

CONTRIBUTING FACTORS	PERCENT OF TOTAL: WORK ZONE ACCIDENTS	PERCENT OF TOTAL: STATEWIDE ACCIDENTS
Human		
Unsafe Speed	10.4	8.0
Failed to Yield Right-of-Way	14.9	16.3
Following Too Close	11.6	4.3
Improper Passing	1.2	1.3
Disregard Traffic Controls	3.0	2.7
Turning Improperly	1.8	2.7
Alcohol Involvement	3.9	6.2
Drug Involvement	0.1	0.2
Sick	0.0	0.1
Fell Asleep	1.4	1.0
Lost Consciousness	0.1	0.2
Driver Inattention	31.5	29.1
Distraction	2.7	1.9
Physical Disability	0.1	0.3
Vehicular		
Brakes Defective	1.4	2.0
Headlights Defective	0.0	0.1
Other Lighting Defects	0.2	0.3
Steering Failure	0.3	0.4
Tire Failure/Inadequate	0.7	0.9
Tow Hitch Defective	0.3	0.1
Over or Improper Load	0.2	0.2
Oversized Load	0.1	0.1
Environmental		
Animal's Action	0.0	1.8
Glare	0.3	0.7
View Obstructed/Limited	2.0	3.6
Debris in Roadway	0.7	0.4
Improper/Non-Working Traffic Controls	0.2	0.2
Shoulders Defective	0.6	0.3
Holes/Deep Ruts/Bumps	0.8	0.2
Road Under Construction/Maintenance	100.0	0.4
Improperly Parked Vehicle	0.3	0.5
Fixed Object	0.1	0.2
Slippery Surface	1.7	10.3
Water Pooling	0.3	0.6

TABLE 5 ACCIDENTS BY TYPE OF WORK ZONE

TYPE OF WORK ZONE	NUMBER OF ACCIDENTS	PERCENT OF TOTAL	PERCENT OF KNOWN
Construction	1104	54.8	69.4
Maintenance	297	14.8	18.7
Utility	62	3.1	3.9
Maintenance or Utility	127	6.3	8.0
Undetermined	423	21.0	-

TABLE 6 FACTORS CONTRIBUTING TO WORK ZONE ACCIDENTS

FACTOR	NUMBER OF ACCIDENTS	PERCENT	SEVERITY INDEX
Congestion	484	24.0	2.12
Restricted Lane Width	188	9.3	1.76
Struck or Avoiding Construction Equipment	113	5.6	1.71
Material such as Gravel or Oil on Roadway	108	5.4	2.47
Related to Flagger (such as Communication Problem) or Construction Worker	107	5.3	2.23
Vehicle Merging Too Late	104	5.2	1.64
Uneven Pavement (including Potholes and Pavement Removal)	78	3.9	2.58
Vehicle Travelling on Lane Closed to Traffic	54	2.7	2.19
View Obstructed	53	2.6	1.74
Pavement Dropoff (Shoulder)	52	2.6	3.11
Lane Blocked	51	2.5	1.41
Struck by Construction Vehicle or Equipment	45	2.2	1.47
Lack of Proper Traffic Control	34	1.7	1.74
Ran off Road in Detour	30	1.5	2.92
No Merge Lane	25	1.2	2.28
Manhole Cover	12	0.6	1.62
Water Pooling	9	0.4	3.61

When adequate information was available, the location of the accident in the work zone was determined (see Table 8). The majority of accidents occurred in the work area, followed by accidents in the transition.

In the 4-year study period, there were 18 accidents involving a pedestrian or construction worker. Five of these accidents involved a pedestrian, nine involved a construction worker, and four involved a flagger. These 18 accidents resulted in 2 fatalities.

A high percentage of accidents occurred in work zones involving trucks—either a single unit or combination truck. The percentage of work zone accidents involving trucks was 25.7 percent compared with 9.6 percent of all accidents. A work zone was listed as a factor in 0.4 percent of all accidents compared with 1.0 percent of all truck accidents. The severity of accidents involving trucks in work zones was higher than statewide truck accidents. The percentage of injury or fatal accidents was about 29 percent for work zone accidents compared with 19 percent for all truck accidents.

Case Study Locations

As previously noted, 20 case study locations were selected from a wide range of projects. Even though the types of projects varied considerably, most traffic control operations were categorized as either single-lane closures on multilane roadways (eight projects) or two-lane, two-way operations (five projects). Two of the eight projects involving single-lane closures also included multilane closures on multilane roadways. There were three bridge construction projects with two-lane detours, and four projects involving two-lane roadway reconstruction, which necessitated diversion of the traffic from old to new sections of road and then back to the old sections at various times in the project. Two of the four projects involving two-lane reconstruction also included single-lane closures with the use of temporary traffic signals. The project beginning and ending dates showed that work was accomplished between July 1985 and July 1988.

Additional information relating to maintaining and controlling traffic was obtained. The contract bid proposals showed that maintenance and control of traffic was bid as a lump sum item on all contracts with incidental traffic control devices also included for several projects. Incidental traffic control devices bid separately in the various contracts included flashing arrows, pavement markings, temporary traffic lights, temporary guardrail, concrete barrier walls, variable message signs, and tubular separation devices.

The analysis of accidents at case study locations included the review and summary of accidents for 3 years before construction and the time period during construction. An effort was also made to extend the appropriate roadway section length to include accidents in the advance warning area. This made it necessary to extend the project limits 1 mi in each direction for the purpose of accident data collection.

One of the basic means of evaluating the overall effectiveness of traffic control at a work site is to compare accident statistics for some period before the work begins with a similar period during the work activity. The periods of analyses were 3 years before and during the construction work. In some cases, the time period of work zone activity was greater than 1 year, hence, the before period of analysis was limited to three complete years of before data. Table 9 presents a summary of accident rates for each of the case study locations.

Accident rates for the 19 case study locations (data were not available for CR-5001 in Harrison County), as presented in Table 9, vary from 35 accidents per 100 million vehicle miles (acc/100 mvm) at Location 15 (Audubon Parkway in Henderson County) to 1,603 acc/100 mvm at Location 11 (KY-1974 in Fayette County). Table 9 also presents statewide average and critical accident rates for each highway type, which were determined previously (*4*). In general, the critical rate

TABLE 7 ACCIDENT SEVERITY VERSUS SEVERAL VARIABLES

VARIABLE	CATEGORY	PERCENT FATAL OR SERIOUS INJURY	PERCENT INJURY OR FATAL ACCIDENTS	SEVERITY INDEX
Type of Work Zone	Construction	8.2	29.4	2.25
	Maintenance	6.4	30.0	2.13
	Utility	3.2	29.0	1.92
Location in Work Zone	Advance Warning	8.8	37.2	2.46
	Transition	6.3	22.6	1.94
	Work Area	8.2	31.5	2.28
Type of Accident	Intersection	4.0	17.7	1.68
	Road Section or Mid-Block	7.7	29.7	2.21
	Rear End	6.0	30.4	2.12
	Head On	31.3	61.2	4.47
	Same Direction Sideswipe	2.8	10.5	1.43
	Opposite Direction Sideswipe	6.2	26.2	2.02
	Enter or Leave Entrance	2.0	18.0	1.57
	Pedestrian	66.7	100.0	7.50
	Fixed Object	12.0	44.4	2.83
	Collision-Not Fixed Object	6.8	22.9	1.98
	Single Vehicle-Run Off Road	15.0	55.4	3.29
	Overturned in Roadway	11.8	70.6	3.47
	Vehicle Backing	0.0	8.3	1.21
	Bridge Related	8.7	30.4	2.22
	Interchange Ramp	8.9	28.9	2.26
	Miscellaneous	0.0	0.0	1.00
Vehicle Type	Truck Involved	8.7	28.9	2.25
	Truck Not Involved	6.5	28.1	2.10
Light Condition	Daylight	6.2	25.3	2.00
	Dawn-Dusk	11.5	37.7	2.63
	Darkness-Lighted	5.3	24.4	1.93
	Darkness-No Lights	12.0	43.8	2.82
Land Use	Rural	9.8	35.2	2.47
	Business	2.6	20.6	1.67
	Residential	6.7	21.8	1.95
Year	1983	7.8	28.1	2.17
	1984	8.3	30.3	2.26
	1985	5.3	27.8	2.01
	1986	6.9	26.7	2.08

TABLE 8 ACCIDENTS BY LOCATION IN WORK ZONE

LOCATION IN WORK ZONE	NUMBER OF ACCIDENTS	PERCENT OF TOTAL	PERCENT OF KNOWN
Advance Warning	113	5.6	8.3
Transition	159	7.9	11.7
Work Area	1,089	54.1	80.0
Unknown	652	32.4	-

TABLE 9 ACCIDENT RATES FOR CASE STUDY LOCATIONS COMPARED TO STATEWIDE AVERAGE AND CRITICAL RATES

LOCATION NUMBER	ROUTE	COUNTY	HIGHWAY TYPE	ACCIDENT RATES (ACC/100 MVM) BEFORE	DURING	STATEWIDE AVERAGE	STATEWIDE CRITICAL	PERCENT CHANGE BEFORE-DURING
1.	I65	Hardin	Rural, Interstate	48	56	69	84	16.6
2.	I65	Hardin	Rural, Interstate	94	99	69	81	5.3
3.	I75	Whitley Laurel Rockcastle	Rural, Interstate	50	66	69	74	32.0
4.	Mt. Pkwy.	Clark Powell	Parkway	68	88	78	96	29.4
5.	CR 5001	Harrison	Rural, Two-Lane	-	-	-	-	-
6.	US 31E	Nelson	Rural, Two-Lane	249	470	302	428	88.8
7.	US 27	McCreary	Rural, Two-Lane	220	76	302	401	-65.5
8.	US 42	Boone Gallatin	Rural, Two-Lane	527	1322	302	613	150.9
9.	KY 90	Metcalfe	Rural, Two-Lane	186	284	302	397	52.7
10.	KY 90	Barren	Rural, Two-Lane	131	97	302	351	-26.0
11.	KY 1974	Fayette	Urban, Undivided Four-Lane	946	1603	802	963	69.5
12.	US 27	Harrison	Rural, Two-Lane	146	211	302	422	44.5
13.	KY 80	Floyd	Rural, Divided Four Lane	370	542	166	215	46.5
14.	Mt. Pkwy.	Powell	Parkway	83	105	78	105	26.5
15.	Adbn Pkwy.	Henderson	Parkway	50	36	78	118	-28.0
16.	WK Pkwy.	Ohio	Parkway	74	137	78	115	85.1
17.	I75	Scott	Rural, Interstate	44	73	69	88	66.0
18.	I75	Whitley Laurel	Rural, Interstate	59	56	69	82	-5.1
19.	WK Pkwy.	Muhlenburg Ohio	Parkway	76	117	78	97	54.0
20.	BG Pkwy.	Nelson Washington	Parkway	87	66	78	115	-24.1

for a highway type is calculated using statistical tests to determine whether the accident rate for a specific class of highway is abnormally high compared with a predetermined average for highways with similar characteristics. For the types of highways included as case study locations, the statewide average rates ranged from 69 acc/100 mvm for rural Interstates to 802 acc/100 mvm for four-lane, undivided roads in urban areas. Critical rates ranged from 74 acc/100 mvm for a section of I-75 in Whitley and Laurel counties to 963 acc/100 mvm for KY-1974 (Tates Creek Road) in Fayette County.

At 14 of the 19 case study locations where accident rates were calculated, rates were less for the 3-year before period than during the time of construction. The five locations where rates were greater before than during construction included

1. Location 7, US-27 in McCreary County,
2. Location 10, KY-90 in Barren County,
3. Location 15, Audubon Parkway in Henderson County,
4. Location 18, I-75 in Whitley and Laurel counties, and
5. Location 20, Bluegrass Parkway in Nelson and Washington counties.

There were not large differences when before rates exceeded during rates except at the site on US-27 in McCreary County. Here, the accident rate before construction was 220 acc/100 mvm as compared with 76 acc/100 mvm during construction. The project covered 3.8 mi and the average number of accidents in the before period was 11/year compared with 5/year during construction. This project was the only location of the five where numbers of accidents before were much greater than during construction. Of the five locations where before rates exceeded during rates, only the Bluegrass Parkway site had rates greater than the statewide average. However, the rate at the Bluegrass Parkway site was less than the statewide critical rate for parkways. Numbers of accidents were tabulated for total days of construction, which in some cases exceeded a complete year.

Of 14 locations where accident rates during construction exceeded those before construction, 10 had rates during construction that exceeded statewide averages for their respective highway type. In addition, 6 of the 14 locations had rates during construction that exceeded statewide critical rates. Of those 10 locations where rates during construction exceeded statewide averages, there were also five sites where rates before construction exceeded statewide averages. This indicates that there were some problems at these locations before construction began. In addition, there were two locations (I-65 in Hardin County and KY-80 in Floyd County) where the accident rate before construction also exceeded the critical accident rate for similar highway types. Part of the accident problem at the I-65 location could have been related to construction activity that apparently took place during the before period of analysis. In the before period, there were 29 construction-related accidents (average of 10 per year) as compared with 9 during the period of construction.

Only four case study locations had accident rates during construction that exceeded the statewide critical rate and the comparable before period that did not exceed the statewide critical rate. These locations were

1. Location 6, US-31E in Nelson County,
2. Location 8, US-42 in Boone and Gallitin counties,
3. Location 11, KY-1974 in Fayette County, and
4. Location 19, Western Kentucky Parkway in Muhlenburg and Ohio counties.

At Locations 6 and 8, there were no work zone accidents in either the before or during periods of analysis. Problems thus related to factors other than construction activity. However, at Location 11 (KY-1974 in Fayette County), there were 10 construction-related accidents identified from a total of 102 accidents during the construction period. This location was the only urban site among the 20 locations and most of the accidents were related to congestion. At Location 19 (Western Kentucky Parkway in Ohio County), 9 of 34 accidents were identified as construction-related during the construction period. In both cases, there were no construction-related accidents during the before period.

Additional analyses were performed with emphasis on accidents related to work zones. Those accidents with road under construction listed as a contributing factor were tabulated for each case study location. Most work zone accidents occurred during the day when road surfaces were dry. There were 69 property damage accidents, 37 injury accidents, and 1 fatal accident. Total vehicles involved were 180, which means that most collisions involved multiple vehicles. Of the 99 work zone accidents, 78 (79 percent) occurred on sections of the road categorized as straight and level or straight and grade. Of the 180 vehicles involved in 99 accidents, 131 were cars and 32 were trucks.

The analysis of types of accidents showed that the most frequently occurring were sideswipes and rear-end collisions. There were also a large number of collisions with fixed or nonfixed objects. Driver inattention was the most frequently listed contributing factor, followed by failure to yield right-of-way and following too close.

Previously discussed were case study locations where accident rates during construction exceeded the statewide critical accident rate. Location 11 (KY-1974 in Fayette County) and Location 19 (Western Kentucky Parkway in Ohio County) were cited as possible problem locations because of the relatively large number and high rate of work zone accidents. KY-1974 in Fayette County is in an urban area with high volumes of traffic and the types of accidents are representative of that type of congested area (rear end collisions, sideswipes, vehicles leaving private drive). Somewhat in contrast is the location on the Western Kentucky Parkway, which is representative of a low-volume, rural road. Most work zone accidents at this location were run off road, or collisions with an object.

Traffic control at the work zone was documented for 18 of the 20 sites. Signs and markings appeared to be in general conformance with the *Manual on Uniform Traffic Control Devices* (MUTCD) and the Kentucky Department of Highways' Standard Drawings. Results from the field inspections included (a) a list of signs and devices used, (b) photographs showing the sequence of control devices approaching the projects, and (c) applicable standard drawings or figures from the MUTCD as referenced in the project traffic control plan.

The most common type of project included in this analysis was the single-lane closure on a multilane roadway (Locations 3, 4, 11, 18, 19, and 20). An example of this type of operation was the spot pavement replacement and joint sealing projects on I-75 in Whitley and Laurel counties (Location 3).

Another type of traffic control operation that was used on the two I-65 projects in Hardin County (Locations 1 and 2) was multilane closures on a multilane roadway. These two projects were a combination of single-lane and multiple-lane closures. Less frequently used, but requiring considerable attention in terms of traffic control, is the two-lane, two-way operation (TLTWO). Included as case study locations were five of this type (Locations 13, 14, 15, 16, and 17). A wide range of devices was used to separate the two directions of traffic flow at the locations inspected. At a culvert failure repair site on KY-80 in Floyd County (Location 13), metal drums were used as channelizing devices and a concrete barrier as the separation device. At the interchange reconstruction project on Mountain Parkway in Powell County (Location 14), Type II barricades were used as channelizing devices and a concrete barrier was used for separation. Flexible tubular markers were used as separation devices in conjunction with metal drums for channelization at Location 15 (Audubon Parkway in Henderson County) and Location 16 (Western Kentucky Parkway in Ohio County). A unique procedure for a TLTWO project was used on I-75 in Scott County (Location 1). Because two interchanges were being reconstructed near the Toyota development, it was necessary to close one direction of I-75 when the bridge overpasses had to be rebuilt. A decision was made to perform the work during daylight hours and use traffic cones as channelization and separation devices. When work on the bridge required closure of both lanes in one direction on I-75, the cones were set and removed during the same day. Over a 4-month period at one of the interchanges, TLTWO was put in place in 22 days.

Another type of traffic control used on projects evaluated in this study was a two-lane detour. There were three bridge construction projects on two-lane roads that used detours as traffic control (Locations 5, 6, and 8).

The last major type of traffic control evaluated was single-lane closures and traffic diversion on two-lane roadways (Locations 7, 9, 10, and 12). A variety of traffic control

strategies were required to accommodate the necessary lane closures and detours on these projects. This location was somewhat unique in that temporary traffic signals were used at lane closures over bridges.

SUMMARY OF RESULTS AND CONCLUSIONS

That numbers and rates of accidents increase in work zones has been assumed. This may be the case under some conditions; however, there appears to be indications that efforts to create safer work zones have been successful in recent years. Even though the level of construction and maintenance activity is higher and traffic volumes have increased, there have not been significant increases in work zone accidents.

The following is a list of conclusions reached from the analysis of work zone accidents for the period 1983 through 1986:

1. The number of accidents coded on police reports as occurring in work zones has remained at approximately 500/year.
2. Most work zone accidents occur on Interstate routes, which apparently have increased levels of maintenance and construction activity and higher traffic volumes.
3. Work zone accidents are more severe than other accidents. Those types involved water pooling and shoulder-dropoff accidents. Additional analyses showed that accidents during darkness and those involving trucks were more severe. Also more severe were those accidents occurring in the advance warning area.
4. The percentage of work zone accidents involving rear end or same-direction sideswipe was almost three times the statewide percentages.
5. The greatest difference in contributing factors, as recorded by the investigating officers, compared with statewide accidents was the higher percentage of work zone accidents with following too close as a contributing factor.
6. A separate analysis of factors contributing to work zone accidents revealed congestion as the most common factor. Other frequently occurring factors were struck or avoiding construction equipment, material such as gravel or oil on roadway, related to flagger, and vehicle merging too late.
7. In the 4-year period of analysis, there were 18 accidents and two fatalities involving a pedestrian or construction worker.
8. There was a high percentage of accidents in work zones involving trucks (25.7 percent) as compared with all accidents (9.6 percent).

The second phase of the study involved evaluation of traffic control and accident analysis at 20 case study locations. The following is a summary of results and conclusions from the analysis of case study locations:

1. The 20 case study work zone sites were categorized as single-lane closures on multilane roadways (6 sites), multilane closures on multilane roadways (2 sites), two-lane, two-way operations (5 sites), two-lane detours (3 sites), and single-lane closures and route diversions (4 sites).
2. For all 20 projects, traffic control was bid as a lump sum item with several projects also having bids for incidental traffic control devices.
3. Accident analyses included a 3-year period before construction and the time period during construction.
4. Accident rates during construction were calculated and varied from 36 acc/100 mvm on the Audubon Parkway in Henderson County to 1,603 acc/100 mvm on KY-1974 in Fayette County.
5. At 14 of the 19 locations where accident rates were calculated, rates during construction exceeded those in the before period.
6. Of the five locations where before rates exceeded during rates, only Location 20 on the Bluegrass Parkway had rates greater than the statewide average.
7. When analyzing the 14 locations where accident rates during construction exceeded those before construction, 10 had rates during construction that exceeded statewide averages for their respective highway type. In addition, 6 of the 14 locations had rates during construction that exceeded statewide critical rates.
8. Only four case study locations had accident rates during construction that exceeded the statewide critical rate and the before period that did not exceed the statewide critical rate. At two of these locations, there were no work zone accidents, which indicates problems other than construction activity.
9. Numbers and rates of accidents at two locations (KY-1974 in Fayette County and Western Kentucky Parkway in Ohio County) indicated possible work zone problems; however, the traffic control appeared to be standard in both cases.
10. Analysis by accident type showed that the most frequently occurring were sideswipes and rear end collisions.
11. Contributing factors most frequently listed were driver inattention, failure to yield right-of-way, and following too close.
12. Documentation of traffic control at 18 of the 20 locations revealed general conformance with the MUTCD and the Kentucky Department of Highways' Standard Drawings.
13. TLTWOs were used successfully at five case study locations. Of particular interest were the three types of devices (concrete barrier, traffic cones, and flexible tubular markers) used to separate opposite directions of traffic flow.

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Safety of One-Way Urban Streets

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The relative safety of one-way streets as compared to two-way streets was studied by comparing accident rates for the two types of streets in one city during the same time period (a cross-sectional design). The study population consisted of all single-carriageway streets in Jerusalem and all injury accidents that occurred on these streets during a 3-year period, 1983 through 1985. Streets were grouped according to class—arterial, collector, or local—and location—in the central business district (CBD) and elsewhere. Accident rates by type of accident—pedestrian and other (vehicle)—were compared within each group of streets. Rates were calculated separately for midblock sections and for intersections. The study concentrated on collector and local streets. In general, one-way streets do not contribute to an improvement in safety relative to two-way streets.

One-way streets are widely used as an inexpensive solution to capacity and parking problems, mainly on arterial or collector streets. In residential areas, one-way streets are used to prevent through-traffic, to reduce conflicts at intersections, and to provide more parking space.

The effects of converting to one-way streets were summarized by Parsonson et al. (*1*). Generally, two-way to one-way conversion results in an increase in speed and a decrease in the number of stops and total travel time. On the other hand, volumes and trip lengths are increased (*2–5*). One-way streets and intersections also have fewer potential vehicle conflicts than do two-way systems.

These effects associated with one-way streets have safety implications that may be reflected in the number, type, and severity of road accidents. The decrease in conflicts and stops implies an increase in safety, whereas the increases in speed, volume, and trip length may lead to an increase in accidents.

Studies on the safety of one-way streets are generally of the before-and-after type and deal mostly with arterial or central business district (CBD) streets. Most of the studies report an accident decrease of 20 to 30 percent (*2,4–6*). The number of midblock accidents is generally reduced more than the number of intersection accidents (*7*). The least reduction in accidents is reported for nonsignalized intersections (*5*).

As mentioned, most studies deal with the conversion of CBD or arterial streets from two-way to one-way operation. The current study examines the safety of one-way streets by comparing accident rates on all one-way streets in one city to those on all two-way streets in the same city, for the same time period.

METHODS

Information on all injury accidents in Jerusalem for 1983 through 1985 was extracted from the injury accident file of the Israel Central Bureau of Statistics (ICBS). In addition, a street and junction file was compiled containing the following data items for each street:

- Code of street according to ICBS;
- Type of street—two-way, one-way, or dual carriageway);
- Class or function—arterial, collector, or residential;
- Location—CBD or other; and
- Length and width of street.

Similar information was compiled for intersections. A junction was defined as one-way if at least one of its legs was a one-way street. The class of a junction was determined by the highest class of its legs. The two files were matched so that each accident record was appended by data pertaining to the street or junction on which it occurred. Dual-carriageway streets and junctions were excluded from the file and from subsequent analysis.

No data were available on traffic and pedestrian volumes. Thus, in the first phase of the analysis, only length of streets and number of junctions were used as exposure measures. Accident rates per kilometer and per intersection were compared for one- and two-way locations. In order to control some of the possible differences in exposure between one- and two-way locations, streets were grouped according to class—residential, collector, or arterial—and location—CBD or other—and the analysis was performed within each group. Within each group, accident rates were analyzed by type of accident—pedestrian or vehicle (mostly collisions)—and by severity. Accident rates were analyzed separately for junctions and for road sections.

The ratio of accident rates between one- and two-way locations served as a measure of the relative risk of one-way locations. A ratio smaller than 1 means that one-way streets have fewer accidents than two-way streets. A ratio greater than 1 means that one-way streets have more accidents.

Only 1.5 km of one-way street sections in Jerusalem are classified as arterial (none within the CBD); thus, any results pertaining to arterial one-way streets could not be generalized, and no results on this type of street are presented. As the CBD area consists of only 12 km of streets, results for local and collector streets in the CBD were analyzed together.

In the second phase of the analysis, exposure data of traffic and pedestrian volumes, speeds, and street widths were collected on a sample of streets. These data were used to examine possible differences between one- and two-way streets of the same type and to obtain accident rates per vehicle-kilometer of travel. A stratified random sample was taken of the population of all streets in Jerusalem; streets were grouped according to location (CBD and non-CBD), class (arterial, collector, or local), and type (one-way or two-way). For each

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type, the sampling quota for the different groups was roughly proportional to the total street length, with at least two streets sampled from each group. Data on 43 streets were collected: 22 one-way streets and 21 two-way streets.

A road section adjacent to a junction was chosen at random for each street. All data were collected at this section. These included width of the street, traffic and pedestrian volumes, and free speeds. Crossing pedestrians were counted for 1 hr at three locations—at the crossing (if one was present), on a 50-m strip adjacent to the crossing, and on the next 100-m strip. Vehicles were also counted manually for 1 hr, by type. Speeds were measured for free-flowing traffic only, 100 m from the junction. At least 50 speed measurements were taken on each street.

The hourly counts were transformed into daily volumes using expansion factors derived from appropriate daily distributions. Pedestrian distributions for CBD and non-CBD streets were taken from a previous study (*8*). Daily distributions of traffic volumes were calculated from existing junction or cordon counts for the major activity hours (7:00 a.m. to 7:00 p.m.) and from 24-hr mechanical counts performed as part of the current study on 15 streets in the sample. Separate distributions were used for CBD and non-CBD streets and for two-way and one-way streets. For one-way streets, separate distributions were used according to whether the traffic flow was to or from the CBD.

The characteristics of one- and two-way streets within each group of class and location, as measured on the sample of streets, were compared to determine whether any differences exist that could explain disparity in accident rates. Accident rates per million vehicle-kilometers were calculated for each group of streets, on the basis of traffic volume sample counts. The relative risk, as measured by the ratio of rates, was used to compare the safety of one- and two-way streets. No similar rates could be calculated for intersections, because no volume data were available for them.

RESULTS

Table 1 presents data on street length and number of intersections in Jerusalem by type and class. From 525 km of the streets in Jerusalem, 13 percent are one-way and the rest are two-way. An additional 83 km are dual-carriageway roads. Of 2,473 intersections, 30 percent have at least one leg that is a one-way street.

Only 12 km, or 2.2 percent of the total street length, lies within the CBD boundaries; of this, 45 percent are one-way streets. No one-way arterials are in the CBD. There are 74 intersections in the CBD, about 3 percent of the number of intersections in the city. Of these, 77 percent have at least one one-way leg. The average width of one-way streets was

TABLE 1 LENGTHS OF STREETS (km) AND NUMBER OF INTERSECTIONS IN JERUSALEM

Type of Location	Arterial	Collector	Local	Total
Length of street				
One-way	1.50	9.14	58.16	68.80
Two-way	19.09	57.36	379.90	456.35
No.of Intersections				
One-way	80	239	405	724
Two-way	58	186	1508	1752

TABLE 2 MIDBLOCK ACCIDENTS PER KILOMETER IN NON-CBD AREAS, 1983–1985

Type of Street	Arterial	Collector	Local	Total
Pedestrian Acc.				
One-way	- (19)	3.72(29)	1.00(54)	1.61(102)
Two-way	2.62 (46)	3.12(172)	0.69(259)	1.06(477)
Relative Risk		1.19	1.45	1.51
Vehicle accidents				
One-way	- (10)	2.31(18)	0.65(35)	0.99(63)
Two-way	2.16 (38)	1.81(100)	0.59(221)	0.80(359)
Relative Risk		1.27	1.10	1.24

Numbers in brackets denote number of accidents

TABLE 3 ACCIDENTS PER INTERSECTION IN NON-CBD AREAS, 1983–1985

Type of Junction	Arterial	Collector	Local	Total
Pedestrian Acc.				
One-way	0.53(37)	0.35(73)	0.06(24)	0.20(134)
Two-way	0.35(19)	0.17(31)	0.02(25)	0.04(75)
Relative Risk	1.53	2.04	3.71	4.65
Vehicle accidents				
One-way	1.20(84)	0.50(105)	0.14(53)	0.36(242)
Two-way	0.58(32)	0.38(69)	0.04(58)	0.09(159)
Relative Risk	2.06	1.32	3.53	3.96

Numbers in brackets denote number of accidents

TABLE 4 MIDBLOCK ACCIDENTS PER KILOMETER IN THE CBD (NONARTERIALS, 1983–1985)

	Pedestrian Acc.	Vehicle Acc.	Total
One-way	4.74(25)	1.71(9)	6.45(34)
Two-way	4.79(24)	1.20(6)	5.99(30)
Relative Risk	0.99	1.43	1.08

Numbers in brackets denote number of accidents

TABLE 5 MIDBLOCK ACCIDENTS PER MILLION VEHICLE-KILOMETERS IN NON-CBD AREAS, 1983–1985

Type of Street	Arterial	Collector	Local	Total
Pedestrian Acc.				
One-way	- (19)	0.61(29)	0.73(54)	0.73(102)
Two-way	0.14(46)	0.39(172)	0.49(259)	0.37(477)
Relative Risk	-	1.57	1.49	1.90
Vehicle accidents				
One-way	- (10)	0.38(18)	0.47(35)	0.45(63)
Two-way	0.12(38)	0.23(100)	0.41(221)	0.28(359)
Relative Risk	-	1.68	1.14	1.63

Numbers in brackets denote number of accidents

almost equal to that of the two-way streets. The number of junctions per kilometer of road was also very similar for the two types of street.

During 1983 through 1985, 1,142 injury accidents occurred in midblock sections, 17 percent on one-way streets. During the same period, 712 injury accidents occurred at intersections, 66 percent at one-way junctions. Tables 2 and 3 present accident rates per kilometer and per intersection by type of accident and street class, for one- and two-way locations. Jerusalem has only two sections of one-way arterial streets, with a total length of 1.5 km; therefore, the rates for one-way arterial sections were not displayed. Accident rates were clearly higher on one-way streets for all street classes and accident types, both for midblock sections and for intersections. The relative risks of one- and two-way sections were similar for pedestrian and vehicle accidents, and their magnitude was between 1.1 and 1.5. The relative risks for intersections were generally higher. The ratios for local intersections were much higher, 3.5 and 3.7 for pedestrian and vehicle accidents, respectively.

For the CBD, the analysis pertains to local and collector streets only, because there are no one-way arterials within the CBD. Accident rates per kilometer were similar for both types of streets. The relative risk, which was 1.1 for all accidents, was 0.99 for pedestrian accidents and 1.43 for vehicle accidents. However, the latter figure was based on a small number of accidents in each group (Table 4).

Tables 5 and 6 present accident rates per million vehicle-kilometers and relative risk by location, class of street, and type of accident for one- and two-way streets. The rates were

TABLE 6 MIDBLOCK ACCIDENTS PER MILLION VEHICLE-KILOMETERS IN THE CBD (NONARTERIALS, 1983–1985)

	Pedestrian Acc.	Vehicle Acc.	Total
One-way	0.49(25)	0.18(9)	0.68(34)
Two-way	0.62(24)	0.15(6)	0.77(30)
Relative Risk	0.80	1.15	0.88

Numbers in brackets denote number of accidents

based on traffic counts on a sample of streets. The results are similar to those obtained for rates per kilometer. One-way streets outside the CBD area had higher pedestrian and vehicle accident rates. The relative risk ranged between 1.1 and 1.7. In the CBD, the relative risk was 1.15 for vehicle accidents and 0.8 for pedestrian accidents.

Table 7 presents the percentage of severe and fatal accidents by street type and function. There was no difference in severity for collector streets; for local streets and junctions, however, one-way accidents were less severe than accidents at two-way locations.

Table 8 presents the average characteristics of one- and two-way streets in the sample by type and location of street, daily traffic volumes, daily flow of crossing pedestrians in a 100-m midblock section, average free-flow speeds, and pavement width. The following paragraphs describe the findings for each attribute.

Traffic Volumes

In the non-CBD area, traffic volumes on one- and two-way streets were similar, and the differences were not statistically significant. In the CBD, the results were not as clear. Although the volumes on two-way streets differed considerably according to class, one-way volumes on collector and local streets were similar and displayed a large variation.

Pedestrian Volumes

Crossing-pedestrian volumes were generally higher on one-way streets in all categories, except for local streets outside the CBD. In this group, the average pedestrian volume on two-way streets was 3.5 times higher than on one-way streets, but the variation was very large, indicating that some streets had an exceptionally high pedestrian count. The original counts revealed one such street. After taking out the outlier count, the average pedestrian volume was 564, slightly higher than the volume on one-way local streets.

Speed

Contrary to expectations, higher speeds were measured on two-way streets than on similar one-way streets in non-CBD areas. In the CBD, higher speeds were measured on one-way streets. However, none of the differences was significant.

Width

One- and two-way streets in each group were of similar width and had no significant differences.

DISCUSSION OF RESULTS

Accident rates per kilometer were compared for one- and two-way streets at midblock and per intersection. The study population consisted of all single-carriageway streets in Jerusalem and all injury accidents that occurred on these streets during a 3-year period (1983–1985). Rates were compared within groups of streets with similar class—arterial, collector, or local. Streets were also divided according to location—in the CBD or elsewhere. The validity of this phase of the analysis was based on the assumption that within each group of function and location, pedestrian and traffic volumes are distributed similarly for one- and two-way streets. Detailed measurements were taken of street widths and lengths, speeds, traffic, and pedestrian crossing volumes, for a random sample of streets. Accident rates per vehicle-kilometer for midblock accidents were calculated on the basis of these measurements.

TABLE 7 PERCENTAGE OF SEVERE AND FATAL ACCIDENTS BY STREET TYPE AND CLASS

Type of Location	Arterial	Collector	Local	Total
Midblock				
One-way	-	19	16	18
Two-way	17	18	27	22
Junction				
One-way	13	14	14	14
Two-way	17	14	20	17

TABLE 8 AVERAGE CHARACTERISTICS OF STREETS BY LOCATION CLASS, AND TYPE

Street Category	Width	Speed (Km/hr)	Traffic Volumes	Pedestrian Volumes
Non CBD				
Local One-w	5.4(1.2)	30.7(6.5)	1252(1371)	407(446)
Local Two-w	5.8(1.1)	33.2(6.9)	1291(1167)	1472(2466)
Collector One-w	8.9(3.8)	34.7(5.6)	5581(4978)	531(267)
Collector Two-w	9.0(2.5)	39.8(6.4)	7346(4478)	286(175)
Arterial One-w	8.1(2.0)	40.7(7.5)	10487(4869)	1447(1251)
Arterial Two-w	12.0(4.7)	40.8(7.8)	16479(5767)	946(944)
Total One-w	6.9(2.7)	33.4(7.5)	3839(4246)	626(685)
Total Two-w	8.0(3.5)	38.8(7.6)	5179(5776)	1018(1796)
CBD				
Local One-w	5.6(1.3)	34.6(6.3)	8760(7160)	2295(695)
Local Two-w	5.9(0.5)	23.8(4.9)	1939(319)	1116(609)
Collector One-w	8.9(0.1)	33.0(6.1)	9062(6048)	3075(1961)
Collector Two-w	8.5(2.1)	32.3(5.8)	13445(966)	1099(1179)
Total One-w	7.3(2.0)	32.8(8.0)	8911(5930)	2685(1383)
Total Two-w	6.8(1.6)	26.6(5.8)	5774(5962)	1110(707)

Numbers in brackets denote standard deviations

When non-CBD locations were compared, accident rates on one-way streets were higher than those on two-way streets for all street types. The relative risk between one- and two-way streets was similar for pedestrian and vehicle accidents. At midblock locations, rates for one-way collector and residential streets were only slightly higher—ratios ranged from 1.1 to 1.7. The rates were similar, whether kilometers or vehicle-kilometers were used for exposure, because traffic volumes on the two types of streets were similar within the same category.

At intersections, ratios were higher. Especially high were the ratios for residential intersections—3.6 and 3.8 for vehicle and pedestrian accidents, respectively. Thus, one-way junctions in residential areas, which are generally not signalized, had almost four times as many accidents as two-way junctions. These findings are in accord with the trend reported in the literature (*5,7*), whereby the change from two-way to one-way street reduces midblock accidents more than intersection accidents. The least reduction in the number of accidents was found at nonsignalized intersections. Possible explanations for the higher accident rates at one-way nonsignalized junctions are the higher speeds and possibly the lower levels of attention on one-way approaches. Moreover, although some conflicts are avoided, the volume increase of other movements may result in an increase in the frequency of other, possibly more severe, conflicts. Unlike midblock rates, the findings for intersections could not be substantiated by incorporating traffic volumes in exposure, because volume data were not available for all intersection approaches. However, the results from the midblock counts indicated that traffic volumes were similar within categories. Also, the definition of one-way intersections was quite crude, as it grouped together intersections with one, two, or more one-way legs; however, this grouping should produce conservative findings.

The analysis for the CBD was based on a small number of accidents, particularly vehicle accidents, of which only 15 occurred on collector and local streets during the study period. Thus, the results pertaining to vehicle accidents in the CBD are of little validity. The class of pedestrian accidents in the CBD is the only one for which there is an indication that one-way streets may be safer—the relative risk per vehicle-kilometer was 0.8, indicating a lower rate of pedestrian accidents on one-way streets.

Analysis of accidents by severity indicates that for local streets and junctions, accidents are less severe at one-way locations than at two-way sites. This finding may reflect the difference in accident type between the two types of location; the majority of vehicle accidents on two-way streets are head-on collisions, while one-way streets are characterized by rear-end collisions. No difference in accident severity was found on collector streets.

The characteristics of one- and two-way streets in each category of class and location, as measured on a sample of streets, were compared to examine possible differences between the two types of streets that may account for the differences in accident rates. The attributes that were examined were width, free-flow speeds, traffic volumes, and crossing pedestrian volumes. It is often stated that narrow streets are made one-way to allow for parking and adequate flow; thus, one-way streets should be narrower as a rule. In fact, within each category of class and location, the two types of street had very similar pavement widths.

Average speeds on one-way streets were slightly lower than on two-way streets for all categories except local streets in the CBD. Differences of 3 to 5 kph were found on local and collector non-CBD streets. Thus, the findings indicate that higher accident rates occur on one-way streets of these two categories even though speeds are lower. As expected, free speeds on CBD streets were significantly lower than on streets outside the CBD (29.7 kph versus 35.6 kph), and speeds increased with class from 30.2 kph on local streets to 40.7 kph on arterial streets. The results do not indicate that higher average speeds are the cause of the differences found in accident rates. Only free-flow speeds were recorded; the possible effect of queues was not considered. Differences may exist in the speed distributions, which were not analyzed at this stage.

Traffic volumes outside the CBD were similar for one- and two-way streets of the same class. Thus, class and location were reasonable proxies for exposure and the results based on vehicle-kilometers traveled were similar to those based on street lengths alone. In the CBD, volumes of one-way local and collector streets were similar on the average and had a large variation. It seems that the classification for one-way streets is not well defined. In other words, some streets that, from a geometrical point of view, are classified as local, function as collector streets, probably because of their enlarged capacity. Since street class is not well defined in the CBD, all CBD streets should probably be grouped together for the purpose of analysis, as was done anyway for considerations of population size. At least for Jerusalem, location and class categories were as good proxies for exposure as average daily traffic volumes.

Crossing-pedestrian volumes were generally higher on one-way streets. Outside the CBD, differences in pedestrian volumes were inconsistent and significant; thus they cannot account for the differences in accident rates. In the CBD, the difference in pedestrian volumes was opposite in direction to that of accident rates. In summary, it seems that different pedestrian volumes could not, in general, explain the different accident rates. On the basis of this study, which compared accident rates on all one-way streets in Jerusalem to the rates on all two-way streets for the same period, it is possible to conclude that one-way streets do not, in general, contribute to an improvement in safety. Accident rates per vehicle-kilometer were higher on one-way streets for all street classes, both for pedestrian and vehicle accidents, with the exception of pedestrian accidents in the CBD. The relative risk of one-way locations was higher for intersections than for midblock sections. The higher accident rates on one-way streets could not be accounted for by differences in pavement width, free speed, or pedestrian volumes.

It seems that although one-way streets may boost traffic and parking capacity, and may increase safety in crowded, high-volume areas such as CBDs, they may not, in general, solve safety problems, especially in residential areas. Flow considerations are usually not relevant for residential areas, where one-way streets are used to increase parking space, reduce through traffic, and lessen conflicts at intersections. Rather, one-way streets may encourage higher travel speeds, which are not desirable in residential areas. They create unexpected patterns of vehicle movement, which may be hazardous to pedestrians, and they cause increases in trip length, thus increasing exposure. In addition, the paucity of enforcement in residential areas may encourage unlawful and dangerous driving in the wrong direction on one-way streets. As pointed out by Landstrom (*9*), restrictions on turns may be a better solution to safety problems at junctions and for reducing through traffic.

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Safety Comparison of Types of Parking on Urban Streets in Nebraska

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Without exception, previous research has found that streets with no parking are safer than similar streets with parking. But the common conclusion of many studies, that parallel parking is safer than angle parking, has been questioned by some researchers, particularly in regard to low-angle parking. The objective of this study was to determine the safest type of parking on urban sections of the state highway system in Nebraska. The accident experience on the urban sections of the state highway system with parking was analyzed. Results of the analysis were used to identify the safest type of parking over the range of traffic, roadway, and land use conditions on the urban system. The accident analysis indicated that (a) parking results in accidents on urban streets, (b) the type of parking affects highway safety even when parking use, land use, and type of roadway are taken into account, (c) the safest type of parking on urban streets is parallel parking, and (d) low-angle parking may be safer than high-angle parking, but it is not as safe as parallel parking. Thus, whenever feasible, parking should not be allowed on urban sections of the state highway system. However, when parking must be allowed, consideration should be given to using parallel parking instead of angle parking.

Several studies (*1*) comparing accidents involving angle and parallel parking have been conducted. Accident reduction factors from 19 to 71 percent were reported after a change from angle to parallel parking. Therefore, the common conclusion of these studies was that parallel parking is safer than angle parking. But none of these studies accounted for the change in accident exposure associated with a change from angle to parallel parking. When angle parking is converted to parallel parking, the accident exposure is reduced, because fewer parking stalls are available after the conversion. In addition, the parking activity may also change with the conversion to parallel parking and the reduction in the number of spaces. Thus, the reductions in accidents that have been experienced with changes from angle to parallel parking may have been caused more by the change in accident exposure than by the change in parking maneuvers associated with the parking configurations.

In 1971, Zeigler (*2*) analyzed the operational characteristics of low-angle and parallel parking patterns. Graphical methods and full-scale vehicle tests were used to evaluate the parking and unparking maneuvers of each pattern. The evaluation indicated that low-angle parking results in less disruption of traffic flow and improved safety for pedestrians entering and exiting parked vehicles. Zeigler (*2*) concluded that low-angle parking provides safer and more efficient traffic operations than parallel parking. However, the study did not include an analysis of accident data related to type of parking.

One of the most comprehensive studies of the safety effects of curb parking was conducted by Humphreys et al. (*3*) in 1978. This study involved the collection and analysis of parking and accident data on over 170 mi of streets in 10 cities. A comparative-type statistical analysis was performed on the accident data using parking type, parking use, abutting land use, and functional classification of the street as the independent variables. Parking use was found to be a primary factor affecting midblock accident rates. Increases in parking use up to 1.5 million annual space hours per mile resulted in higher accident rates. The study also found that an increasing accident rate was generally associated with changes in land use from single-family dwelling to apartment, from apartment to office, and from office to retail. Because each of these changes in land use indicated an increase in parking turnover rates and pedestrian activity, the associated increases in accident rates were deemed appropriate. However, type of parking was found to have no effect on accident rates when parking use, abutting land use, and street classification were taken into account. In other words, angle parking was found to be no more hazardous than parallel parking for similar levels of parking demand, land use, and street type.

Without exception, previous research has found that streets with no parking are safer than similar streets with parking. But the common conclusion of many studies, that parallel parking is safer than angle parking, was brought into question by the findings of Zeigler (*2*) and Humphreys et al. (*3*), particularly with respect to low-angle parking (i.e., 30 degrees or less).

OBJECTIVE AND SCOPE

The objective of this research was to determine the safest type of parking on urban sections of the state highway system in Nebraska. A review of the state highway system was conducted to identify the urban sections that had parking on them. The urban sections with parking were surveyed to obtain information about the type and amount of parking, the roadway and traffic conditions, and the land use characteristics of each section. The accident experience on the urban sections surveyed was analyzed to determine the relationship between highway safety and type of parking. The results of the accident analysis were used to determine the safest type of parking

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over the range of traffic, roadway, and land use conditions found on urban sections of the state highway system.

PARKING INVENTORY

An inventory of the state highway system was conducted to determine the types and amounts of parking on the urban sections of the system. The roadway, traffic, and land-use characteristics of each section with parking were also determined. These data were used in the accident analysis to examine the relationship between accident experience and type of parking.

Procedure

A listing of all urban sections on the state highway system was obtained from the roadway inventory computer file maintained by the Nebraska Department of Roads (NDOR). This listing was reviewed to identify urban sections that might have parking on them, on the basis of number of traffic lanes and roadway width. Sections that were obviously too narrow to provide parking were eliminated from further consideration. Approximately 603 sections, comprising over 274 mi of roadway, were identified as possibly having parking. The NDOR photologs of these sections were examined to determine which of them actually had parking. A total of 491 sections were found to have parking. These sections were in 126 cities and comprised 183 mi of roadway. Surveys of the sections were made to collect the necessary information about the parking, roadway, and land use characteristics. Two types of surveys were used—field and questionnaire surveys.

Field Surveys

To obtain as much first-hand information as possible within the limits of the available resources, the field surveys were made in the cities that had the most sections with parking. Field surveys were conducted in 55 cities, which included all cities with 1980 populations greater than 4,000. Altogether, 260 sections comprising 86 mi of roadway were surveyed in the field. The accidents on these sections accounted for 87 percent of the parking accidents that occurred during 1985 and 1986 on the 491 sections with parking. The following parking and roadway information was recorded for each section: (a) amounts and types of parking, (b) numbers and types of land uses, (c) numbers and lengths of blocks, (d) speed limits, (e) intersection controls, (f) numbers of driveways and alleys, (g) numbers of lanes, (h) directional controls, and (i) roadway alignment. Also the number of each of the following types of land use was counted on each block face: (a) retail, (b) service, (c) office, (d) medical, (e) institutional, (f) industrial, (g) recreational, (h) agricultural, (i) residential, and (j) other.

In addition to these data, parking use on each block face was measured. At the beginning of the field survey in each city, the number of vehicles parked on each block face was counted. A second count was made at the end of the field survey. The time of day that each count was made was also noted. These data were used to estimate the vehicle-hours of parking on each block face. The estimates were computed from parking-use curves for similar block faces. The parking-use curves related percentage of average daily vehicle-hours of parking to time of day. They were developed from the results of parking-use studies, which were conducted on typical block faces in central business districts and residential neighborhoods in cities representative of the following population ranges: below 8,000, from 8,000 to 35,000, from 35,000 to 200,000, and over 200,000.

Questionnaire Survey

Conducting field surveys in all 126 cities that had sections of the state highway system with parking was not possible because of resource limitations. Therefore, a questionnaire survey was conducted to obtain the necessary information from the 71 cities in which field surveys were not made. To keep the questionnaire as short as possible and maximize the likelihood that it would be returned, only information that could not be obtained accurately enough from the photologs was requested. Therefore, the questionnaire was limited to questions about parking layout, use, and restrictions.

The questionnaire consisted of a parking survey form for each block face. Each parking survey form was prelabeled with the name of the city, the highway number, and the block designation. A plat of the city designating each block face was included with the parking survey forms to facilitate proper identification of the block faces. The form was divided into three sections. The first section asked for information about the parking layout on the block face. If the parking stalls were painted, the dimensions of the stalls and their number were requested. If the stalls were unpainted, the type of parking and number of stalls were requested. The second section of the form asked for a count of the numbers of vehicles parked on the block face at 9:00 a.m., noon, and 4:00 p.m. These data were used to estimate the parking use on the block face. The third section of the form asked for information about any parking restrictions that might be in effect on the block face.

The responses to the questionnaire were checked for accuracy by comparing them to the parking data obtained from the photologs. If a discrepancy was found, a letter was sent to the city asking that the particular discrepancy be checked. Unverified data were not used.

Of the 71 cities surveyed, 44 (62 percent) responded to the questionnaire with usable data. These towns accounted for 162 sections comprising 85 mi of roadway. The accident experience on these sections accounted for 10 percent of the parking accidents that occurred during 1985 and 1986 on the 491 sections with parking. Thus, the field and questionnaire surveys together provided the data for 422 of the 491 sections, which amounted to 171 of the 183 mi of urban sections of the state highway system with parking. The accident experience on the 422 sections included 97 percent of the parking accidents that occurred on the 491 sections.

Findings

The 422 urban sections surveyed included 2,336 block faces. Of these block faces, 292 had more than one type of parking

TABLE 1 DISTRIBUTION OF PARKING TYPES

Type of Parking	No. of Stalls	Miles
Painted Parking:		
Parallel	3,036	15.7
Low-Angle	377	1.6
High-Angle	3,259	10.9
Unpainted Parking:		
Parallel	19,536	97.9
Angle	2,678	9.4
Total	28,886	135.5

pattern on them. In order to avoid confounding the results of the study with the effects of uncommon combinations of parking patterns, the block faces with more than one type of parking were not included in the study. Thus, 2,044 block faces, each with only one type of parking, were used. The 2,044 block faces included 28,886 parking stalls on 135.5 mi of street.

Types of Parking

The distribution of the types of parking patterns on the 2,044 block faces with only one type is shown in Table 1. Only 6,672 stalls were painted. The other 22,214 stalls were not painted. Of the painted stalls, 3,036 were for parallel parking and 3,636 were for angle parking. Only 377 stalls were for low-angle parking.

Roadway Type

The distribution of the types of parking by roadway type is presented in Table 2. Parallel parking was the most common parking pattern on all roadway types. On major streets (i.e., one-way; two-way divided; and two-way, multilane, undi-

TABLE 2 DISTRIBUTION OF PARKING TYPES BY ROADWAY TYPE

	Number of Stalls			
Type of Parking	One-Way	Two-Way Divided	Two-Way Multilane Undivided	Two-Way Two-Lane
Painted Parking:				
Parallel	692	320	1,012	1,012
Low-Angle	0	0	0	377
High-Angle	219	20	159	2,861
Unpainted Parking:				
Parallel	926	1,177	1,190	16,243
Angle	0	0	57	2,621
Total	1,837	1,517	2,418	23,114

vided roadways), over 90 percent of the stalls were for parallel parking. Most of the angle parking was on two-way, two-lane roadways. In fact, this was the only type of roadway with all types of parking. Also, it was the only type of roadway with low-angle parking.

Population

The distribution of the types of parking by city population on the major streets and the two-way, two-lane streets is presented in Tables 3 and 4, respectively. Practically all parking on urban sections of the state highway system in cities with populations of 8,000 or more was parallel parking. Angle parking was found primarily on two-way, two-lane streets in cities with populations below 8,000.

Land Use

The distribution of land uses served by the types of parking on the major streets is presented in Table 5. On major streets, the distribution of land uses served by painted parallel and painted angle parking was similar: about two-thirds served by both types were retail, service, and office land uses. The unpainted parallel parking on major streets served mainly residential and retail land uses.

The distribution of land uses served by the types of parking on two-way, two-lane streets is presented in Table 6. On two-way, two-lane streets, both painted parallel and high-angle parking had similar land-use distributions, serving about 75 percent retail, service, and office land uses. The painted low-angle parking and the unpainted angle parking on two-way, two-lane streets had similar land-use distributions, serving mostly retail, office, and other land uses. Residential land uses were most commonly served by unpainted parallel parking.

ACCIDENT STUDY

The accident experience on the urban sections with parking was analyzed to determine the relationship between highway safety and type of parking. The results of the analysis were used to determine the safest type of parking for the conditions on urban sections of the state highway system in Nebraska.

Procedure

Data were obtained from NDOR's computerized accident record system on all reported accidents that occurred during 1985 and 1986, in the 422 urban sections surveyed. The data included the following information for each accident: date, day of week, time of day, reference post of location, directional analysis code, intersection code, severity code, movements of vehicles involved, and directions of travel of vehicles involved. The block within which each accident occurred was

TABLE 3 DISTRIBUTION OF PARKING TYPES BY POPULATION ON MAJOR STREETS

	Number of Stalls		
Type of Parking	Population Below 8,000	Population Between 8,000 & 35,000	Population Over 35,000
Painted Parking			
Parallel	756	551	717
Low-Angle	0	0	0
High-Angle	318	40	40
Unpainted Parking:			
Parallel	820	780	1,693
Angle	19	38	0
Total	1,913	1,409	2,450

Note: Major streets include one-way, two-way divided, and two-way multilane undivided streets.

TABLE 4 DISTRIBUTION OF PARKING TYPES BY POPULATION ON TWO-WAY, TWO-LANE STREETS

	Number of Stalls		
Type of Parking	Population Below 8,000	Population Between 8,000 & 35,000	Population Over 35,000
Painted Parking:			
Parallel	897	115	0
Low-Angle	377	0	0
High-Angle	2,861	0	0
Unpainted Parking:			
Parallel	15,516	529	198
Angle	2,583	38	0
Total	22,234	682	198

found by comparing the reference post of the accident location with those at the ends of the blocks. Once the block was found for an accident, the block face on which it occurred was determined from the type of accident and the directions of travel and the movements of the vehicles involved in the accident. After the accidents were assigned to the block faces, the number of accidents for each accident type was computed for each block face.

Regression Analysis

Regression analysis was conducted to determine the relationship between safety and type of parking. The stepwise regression analysis procedure of the SAS system (*4*) was used to evaluate numerous regression models. Separate regression runs were made for each type of street. The dependent variables in the models investigated were total number of nonintersection accidents and total number of parking accidents. The independent variables tried included type of parking, parking use, number of parking stalls, speed limit, average daily traffic (ADT), roadway alinement, roadway width, block length, percentages of land-use types, and land-use density.

None of the models was found to adequately explain the relationship between the numbers of accidents and the type of parking on a block face. Although some statistically significant variables were found, the highest coefficients of determination were about 0.15. One reason the regression analysis failed to find any relationships was that the data were not well distributed over the ranges of the independent variables. Instead, the data were clustered, with only a few combinations of the independent variable values being represented. For example, all of the low-angle parking was found on two-way, two-lane streets in cities with populations less than 8,000, and about 90 percent of the low-angle parking was on streets with ADT below 5,000. Nearly all parking in cities with populations above 8,000 or on two-way, two-lane streets with ADT above 5,000 was parallel parking.

Accident Rates

Therefore, the relationship between highway safety and the type of parking was determined by simply comparing the mean accident rates of the parking types on each type of roadway. Nonintersection accident rates and parking accident rates were computed. The parking accident rates included only collision with parked vehicles and parking maneuver accidents. It was not possible to identify parking-related accidents, such as rear-end and sideswipe collisions caused by parking activity, because the original accident reports were not available to the study. Consequently, the parking accident rates may underestimate the safety effects of parking.

Two measures of exposure were used to compute the rates. One was millions of vehicle-miles of travel, which is the measure of exposure commonly used to compute accident rates for roadway sections. However, this measure does not account for the level of parking activity on the sections. To account for the level of parking activity, as well as the amount of travel on the sections, another measure of exposure was also used. This measure was the product of travel and parking use per stall, which was expressed in terms of billions of vehicle-

TABLE 5 DISTRIBUTION OF LAND USES SERVED BY TYPES OF PARKING ON MAJOR STREETS

	Type of Parking				
	Painted			Unpainted	
Land Use	Parallel	Low-Angle[a]	High-Angle	Parallel	Angle
Retail	53%	--	43%	25%	90%
Service	3%	--	4%	2%	0%
Office	12%	--	21%	6%	0%
Medical	1%	--	1%	2%	0%
Institutional	1%	--	1%	2%	0%
Industrial	2%	--	3%	2%	0%
Recreational	2%	--	6%	2%	10%
Residential	9%	--	3%	42%	0%
Other	17%	--	18%	17%	0%
Total	100%	--	100%	100%	100%

Note: Major streets include one-way, two-way divided, and two-way multilane divided streets.

[a]Because there was no low-angle parking on major streets, data are not available for that category.

mile-hours per stall. The parking use used to compute this measure of exposure included only daytime parking, because resources were not sufficient for collecting nighttime parking use. However, the accidents used to compute the accident rates included both daytime and nighttime accidents. Consequently, some of the accident rates based on parking use may be overestimated.

The statistical significance of the differences between the mean accident rates was determined using the Poisson distribution test (*5*). The Poisson distribution test was conducted at the 5 percent level of significance.

Percentage of Parking Accidents

The percentages of parking accidents among the types of parking were compared. The percentage of nonintersection accidents that involved a parked vehicle or a parking maneuver was computed for each type of parking on the major and two-way, two-lane streets. The statistical significance of the differences between the percentages was determined using the normal approximation test. The normal approximation test was conducted at the 5 percent level of significance.

Comparison of Similar Block Faces

In addition to the comparison of the overall accident rates and parking accident percentages, parking types on similar two-way, two-lane streets were compared in an effort to account for the effects of traffic, roadway, and land use characteristics. Block faces with painted parallel, low-angle, and high-angle parking, which had similar characteristics, were identified. The mean accident rates for the painted parallel, low-angle, and high-angle parking on these similar block faces were then computed and compared. Block faces with unpainted parallel and angle parking, which had similar traffic, roadway, and land use characteristics, were also identified. The mean accident rates for the unpainted parallel and angle parking on the similar block faces were then computed and compared.

The Poisson distribution test was used to determine the statistical significance of the differences between the mean

TABLE 8 ACCIDENT EXPOSURE IN 2-YEAR PERIOD

Type of Parking	Major Streets[a]	Two-Way Two-Lane Streets
Travel (million vehicle-miles)		
Painted Parking:		
Parallel	120	22.4
Low-Angle	--[b]	3.85
High-Angle	7.50	23.4
Unpainted Parking:		
Parallel	232	193
Angle	1.91	12.6
Parking Utilization (1,000 vehicle-hours/stall)		
Painted Parking:		
Parallel	2.54	2.78
Low-Angle	--[b]	3.52
High-Angle	1.67	2.78
Unpainted Parking:		
Parallel	1.72	1.24
Angle	1.19	1.38

[a]One-way, two-way divided, and two-way multilane undivided streets.

[b]Data not available, because there was no low-angle parking on major streets.

dents on major streets with painted parallel parking was lower than that on major streets with painted high-angle parking. Similarly, the major streets with unpainted parallel parking had a lower percentage of parking accidents than major streets with unpainted angle parking. However, these differences were not statistically significant.

On two-way, two-lane streets, 56 percent of the nonintersection accidents were parking accidents. Among the painted parking types, low-angle and high-angle parking had significantly higher percentages of parking accidents than the parallel parking. There was no statistically significant difference in parking accident percentages between low-angle and high-angle parking. Of the unpainted parking types, streets with angle parking had a significantly higher percentage of parking accidents than streets with parallel parking.

Comparison of Similar Block Faces

The accident experience of similar block faces with painted parking is compared in Table 12, and that of similar block faces with unpainted parking is compared in Table 13.

Painted Parking A total of 57 similar block faces with painted parallel, low-angle, and high-angle parking on two-

TABLE 9 NONINTERSECTION ACCIDENT RATES

Type of Parking	Major Streets[a]	Two-Way Two-Lane Streets
Accidents Per Million Vehicle Miles		
Painted Parking:		
Parallel	1.65	1.83
Low-Angle	--[b]	3.38
High-Angle	1.20	3.59
Unpainted Parking:		
Parallel	1.32	0.674
Angle	1.57	1.67
Accidents Per 10 Billion Vehicle-Mile-Hours/Stall		
Painted Parking:		
Parallel	6.50	6.58
Low-Angle	--[b]	9.59
High-Angle	7.19	12.9[c]
Unpainted Parking:		
Parallel	7.67	5.44
Angle	13.19[d]	12.10[d]

[a]One-way, two-way divided, and two-way multilane undivided streets.

[b]Data not available, because there was no low-angle parking on major streets.

[c]Significantly higher than the rate for painted parallel parking at the 5% level of significance.

[d]Significantly higher than the rate for unpainted parallel parking at the 5% level of significance.

way, two-lane streets were identified. Six of the block faces had parallel parking, 21 had low-angle parking, and 30 had high-angle parking. The similarity of the block faces was defined in terms of the range of traffic, roadway, and land use characteristics found on the block faces with low-angle parking. All of the block faces were on level, tangent sections of roadway with posted speed limits of 25 mph. The ADT on these streets was between 1,400 and 4,250. The lengths of the block faces were between 300 and 500 ft, and the land-use densities on them were between 4 and 30 land uses per 1,000 ft. The daily parking use on the block faces was between 40 and 190 veh-hr per 8-hr parking day (i.e., from 9:00 a.m. to 5:00 p.m.). The maximum percentages of any one type of land use on the block faces were 100 percent retail, 34 percent service, 67 percent office, 12 percent medical, 17 percent institutional, 50 percent industrial, 50 percent recreational, 40 percent residential, and 56 percent other.

The accident exposure and the accident rates for the similar block faces are presented in Table 12. The nonintersection accident rates for the low-angle and high-angle parking were

TABLE 10 PARKING ACCIDENT RATES

Type of Parking	Major Streets[a]	Two-Way Two-Lane Streets
	Accidents Per Million Vehicle-Miles	
Painted Parking:		
Parallel	0.550	0.848
Low-Angle	--[b]	2.60[c]
High-Angle	0.533	2.91[c]
Unpainted Parking:		
Parallel	0.284	0.264
Angle	0.524	1.11[d]
	Accidents Per 10 Billion Vehicle-Mile-Hours/Stall	
Painted Parking:		
Parallel	2.17	3.05
Low-Angle	--[b]	7.38[c]
High-Angle	3.19	10.5[c]
Unpainted Parking:		
Parallel	1.65	2.13
Angle	4.40[d]	8.04[d]

[a]One-way, two-way divided, and two-way multilane undivided streets.

[b]Data not available, because there was no low-angle parking on major streets.

[c]Significantly higher than the rate for painted parallel parking at the 5% level of significance.

[d]Significantly higher than the rate for unpainted parallel parking at the 5% level of significance.

significantly higher than those for the parallel parking. The parking accident rates for the low-angle and high-angle parking were higher than those for the parallel parking, but only the rates for the high-angle parking were significantly higher. There were no statistically significant differences between the accident rates for the low-angle and high-angle parking.

Unpainted Parking A total of 70 similar block faces with unpainted parking on two-way, two-lane streets were identified: 46 had parallel parking, and 24 had angle parking. The similarity of the block faces was defined in terms of the range of traffic, roadway, and land use characteristics found on the block faces with unpainted angle parking. All of the block faces were on level, tangent sections of roadway with posted speed limits of 25 mph. The ADT was between 4,150 and 14,750. The block faces were between 300 and 500 ft long, and the land use densities were below 35 land uses per 1,000 ft. The maximum parking use on the block faces was 155 veh-hr per 8-hr parking day. The block faces had a maximum

TABLE 11 PERCENTAGES OF PARKING ACCIDENTS

Type of Parking	Major Streets[a]	Two-Way Two-Lane Streets
Painted Parking:		
Parallel	33%	46%
Low-Angle	--[b]	77%[c]
High-Angle	44%	81%[c]
Unpainted Parking:		
Parallel	21%	39%
Angle	33%	67%[d]

[a]One-way, two-way divided, and two-way multilane undivided streets.

[b]Data not available, because there was no low-angle parking on major streets.

[c]Significantly higher than the percentage for painted parallel parking at the 5% level of significance.

[d]Significantly higher than the percentage for unpainted paralled parking at the 5% level of significance.

of 25 percent service land uses and up to 100 percent of retail, office, medical, institutional, industrial, recreational, residential, and other land uses.

The accident exposure and the accident rates for the similar block faces are presented in Table 13. The nonintersection and parking accident rates for the angle parking were higher than those for the parallel parking. There were no statistically significant differences between the nonintersection accident rates for the angle parking and the nonintersection accident rates for the parallel parking. However, the parking accident rates for the angle parking were significantly higher than the parking accident rates for the parallel parking.

CONCLUSIONS

Parking on urban streets obviously results in accidents. None of the types of parking studied had a zero parking accident rate. Overall, 26 percent of the nonintersection accidents on major streets and 56 percent on two-way, two-lane streets were parking accidents. Therefore, whenever practical, parking should not be allowed.

However, parallel parking is the safest type of parking on urban sections of the state highway system in Nebraska. Parallel parking was consistently found to have lower accident rates and lower percentages of parking accidents than low-angle or high-angle parking over the range of traffic, roadway, and land use conditions on these roadways. In many cases, the accident rates and parking accident percentages for low-angle and high-angle parking were significantly higher than those for parallel parking. Therefore, when parking must be allowed on urban sections of the state highway system, parallel parking should be used instead of angle parking whenever feasible.

Another conclusion of the study was that type of parking affects accident rates. Contrary to the findings of others (*3*), the type of parking was a factor, even when parking use, abutting land use, and type of street were taken into account. In fact, the differences between the accident rates for parallel parking and those for angle parking were more likely to be significant when these factors were considered, particularly on two-way, two-lane streets.

Finally, low-angle parking may be safer than high-angle parking on two-way, two-lane streets. In most cases considered, the accident rates for low-angle parking were lower than those for high-angle parking. However, in no case was there a statistically significant difference in the accident rates. Also, on two-way, two-lane streets, the percentage of parking accidents for low-angle parking was not significantly different from that for high-angle parking. Although low-angle parking may be safer than high-angle parking, it is not as safe as parallel parking.

The conclusions of this study were based on only 2 years of accident experience on urban sections of the state highway system in Nebraska. Although a number of statistically significant differences in safety effects were found among the different types of parking, the conclusions of this study must be substantiated by further study before they can be recom-

TABLE 12 COMPARISON OF TYPES OF PAINTED PARKING ON SIMILAR BLOCK FACES ON TWO-WAY, TWO-LANE STREETS

Variable	Type of Parking: Parallel	Low-Angle	High-Angle
Accident Exposure (two-year period)			
Number of Block Faces	6	21	30
Number of Stalls	82	313	562
Travel (million vehicle-miles)	0.708	3.09	4.24
Parking Utilization (1,000 veh-hr/stall)	2.82	3.45	3.12
Non-Intersection Accidents			
Number	1	12	19
Accidents Per Million Vehicle Miles	1.41	3.88[a]	4.48[a]
Accidents Per 10 Billion Veh-M-H/Stall	5.00	8.96[a]	14.4[a]
Parking Accidents			
Number	1	9	16
Accidents Per Million Vehicle-Miles	1.41	2.91	3.77[a]
Accidents Per 10 Billion Veh-M-H/Stall	5.00	8.44	12.1[a]

[a]Significantly higher than the rate for painted parallel parking at the 5% level of significance.

mended as general parking policy. Additional research should avoid the limitations of this study by considering accident severity, parking-related accidents, and nighttime parking use.

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TABLE 13 COMPARISON OF TYPES OF UNPAINTED PARKING ON SIMILAR BLOCK FACES ON TWO-WAY, TWO-LANE STREETS

Variable	Type of Parking: Parallel	Angle
Accident Exposure (two-year period)		
Number of Block Faces	46	24
Number of Stalls	621	452
Travel (million vehicle-miles)	12.1	3.45
Parking Utilization (1,000 veh-hr/stall)	3.23	3.23
Non-Intersection Accidents		
Number	11	6
Accidents Per Million Vehicle Miles	0.909	1.74
Accidents Per 10 Billion Veh-M-H/Stall	2.81	5.39
Parking Accidents		
Number	3	5
Accidents Per Million Vehicle-Miles	0.248	1.45[a]
Accidents Per 10 Billion Veh-M-H/Stall	0.768	4.49[a]

[a]Significantly higher than the rate for painted parallel parking at the 5% level of significance.

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Role of Road User and Roadway Geometrics in Road Accidents in Jordan

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Jordan's road network has been one of the fastest growing systems in the area and promises to continue developing in the years to come. In order to continue this road development, the state of Jordan is searching for means to improve road safety and management practices. Following numerous requests made by public officials for aid and guidance in the road safety field, several research teams were formed. The aim of these teams is to undertake research in Jordan with a view to establishing the nature and extent of its traffic accident problems, and in the longer term to assess the effectiveness of remedial measures. Some of the major findings of these research teams are described. Special emphasis is given to the effect of road users and geometrics on road accidents. Road users were found to be responsible for about 95 percent of all accidents.

Statistics in every part of the world have shown that economic losses and human suffering resulting from road accidents can be large and difficult to bear by some countries. In the past few years, Jordan has experienced an accelerated stage of economic growth that resulted in a large increase in car ownership, consequently resulting in an increase in accident rates (*1*).

Figure 1 shows accident rates and associated human losses for the period between 1970 and 1985. Statistics shown indicate large losses for a small country like Jordan with a population of about 3 million. An increase of 464 percent in the number of accidents is observed for 1985 over 1970. This increase was mainly because of car ownership, which increased 908 percent.

In 1979, road accidents were the fourth most important cause of death, causing over 5 percent of all deaths recorded. However, in 1962 road accidents ranked 11th in importance and accounted for only 1.3 percent of recorded deaths. Excluding the very young and elderly, road accidents were the second most important cause of death and have become a serious social problem. Preliminary analysis indicated that road accidents cost the country 34 million Jordanian Dinars (about $86 million in 1985 dollars) in 1985. This amount represents about 5.6 percent of Jordan's gross national income.

Half the accidents in Jordan occur in the capital city of Amman and its suburbs. This statistic may be related to economic and population concentration in Amman. Analysis of accident records indicates that there is a high proportion of pedestrian casualties and a high proportion of children pedestrian casualties. An increase in number of accidents is also observed during summer months because of the influx of drivers from other countries.

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ASSESSMENT OF THE MAIN REASONS OF ROAD ACCIDENTS

The growth in road accidents results from many reasons, besides the increase in population and car ownership. These explanations range from poor traffic management, inadequate road design, and poor road user behavior to lack of coordination among concerned parties.

A study (*3*) conducted by Jordan's Ministry of Transport reviewed the geometric design elements of some hazardous locations. Data collected in this study did not permit the assessment of accident rates related to various geometric design elements because the part of the accident form relevant to road geometrics was not filled by the police officer in most of the records. However, comparisons were made between the number of accidents occurring in 1 year on roads of different geometric features. Roads were selected such that all other characteristics were similar except for one geometric feature. Major findings are shown in Figure 2.

The behavior of road users is generally considered to be the major cause of road accidents in Jordan. Although accidents are unlikely to arise from a single cause, the road user is a predominant influence. Figure 3 shows the rates associated with some common human errors averaged over a period of 5 years (1979 through 1983). The most frequent road user

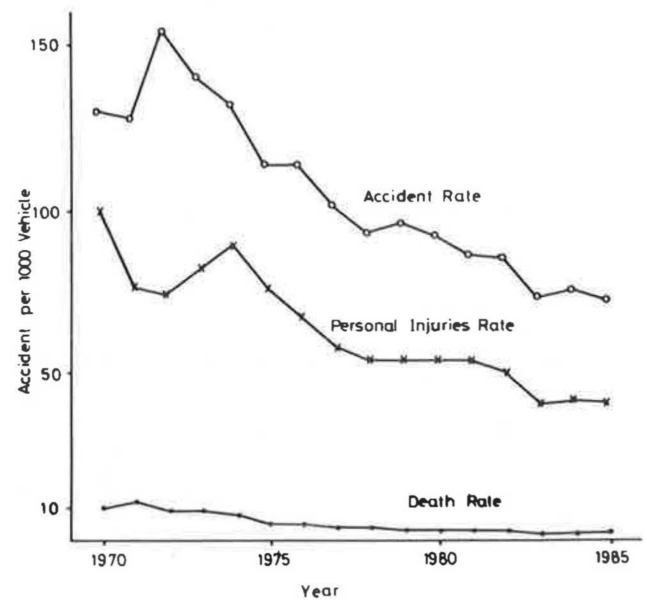

FIGURE 1 Accident rates in Jordan (*2*).

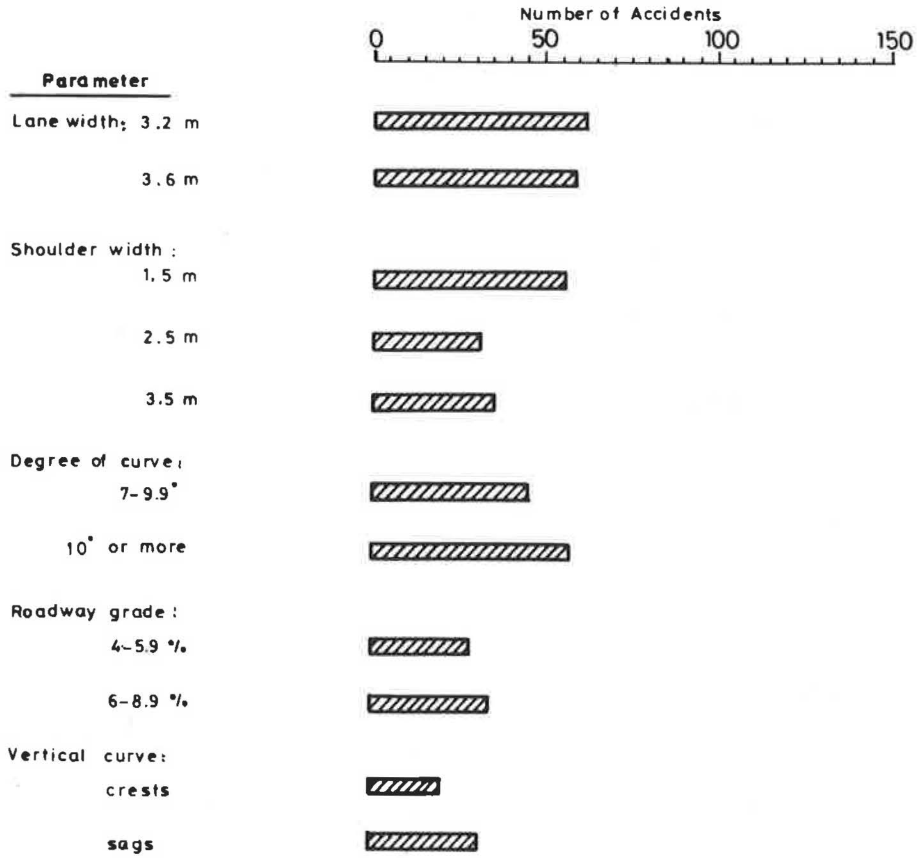

FIGURE 2 Accident frequencies related to geometric design elements (*2*).

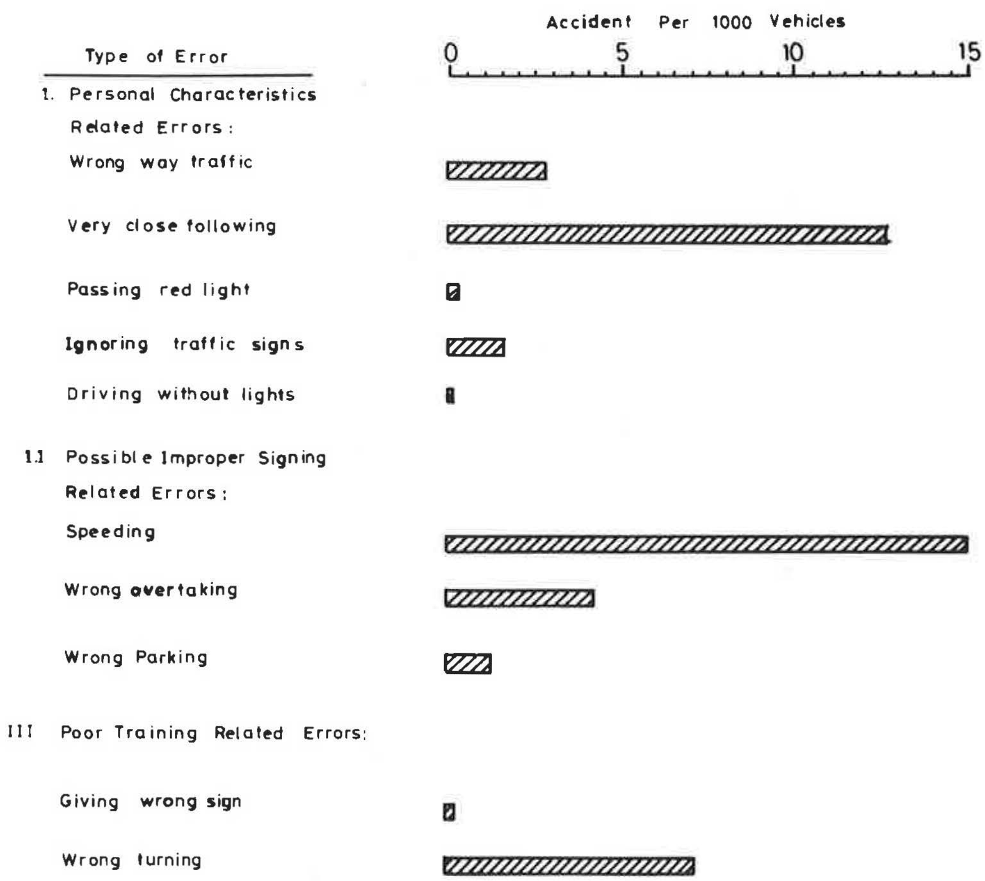

FIGURE 3 Accident rates caused by common human errors (*2*).

TABLE 1 ROLE OF DIFFERENT REASONS IN ROAD ACCIDENTS (*1*)

Reason of Accident	Percentage of Total Accidents Averaged over 5 years
Human Errors	65.00%
Combined human and road elements	24.00%
Combined human, and vehicle elements	4.50%
Combined human, road, and vehicle elements	1.25%
Road elements	2.50%
Road and vehicle elements	0.25%
Vehicle elements	2.50%

TABLE 2 PERCENTAGE OF DIFFERENT ACCIDENT TYPES (*1*)

Accident	Year						
Type	1980	1981	1982	1983	1984	1985	Ave.
Two Cars Collision	55	55	57	57	59	58	56.8
One Car	9	10	10	10	8	9	9.3
Pedestrian	28	27	25	25	24	24	25.5
Fixed object	5	5	5	6	6	7	5.7
Others	3	3	3	2	3	2	3.0

TABLE 3 NUMBER OF CASUALTIES BY PERSON INVOLVED (*1*)

Year	Driver	Passenger	Pedestrian
1980	1715	2381	3609
1981	2046	2869	3979
1982	2346	3084	4014
1983	2063	2758	3799
1984	2316	3025	4097
1985	2409	3109	4115

TABLE 4 ESTIMATED ROAD ACCIDENT COST

Year	Population (million)	Car owner-Ship (Veh/capita)	Number of Accidents	Annual Income (JD/capita)	Annual Accident Cost (Million JD)	Percentage of Gross National Income
1980	2.23	0.06	12433	171.7	12.66	1.4
1985	2.63	0.12	16078	234.0	34.38	5.6
1990	3.09	0.20	37527	306.0	82.51	8.7
1995	3.62	0.30	57093	402.2	184.45	12.7
2000	4.22	0.41	78559	507.4	372.91	17.4

Current equivalence: one JD = 1.5 U.S. Dollar

errors are speeding, tailgating, and turning wrong. Table 1 presents the role of the different reasons in contributing to road accidents. Violation of traffic rules by most drivers and pedestrians is one of the major reasons for the increase in the number of road accidents. Generally, accident data for Jordan reveal that pedestrians and children are at particular risk. Drivers frequently display a lack of courtesy toward children and pedestrians and this probably contributes to the high accident rate. Table 2 presents the percentage of different accident types between 1980 and 1985. These statistics reveal that two-car collisions have the highest percentage among all types for all years. Although this statistic is a common finding, it is attributed mainly to the high rate of traffic violations. Table 2 also indicates that pedestrian accidents rank second as a percentage of all accidents, whereas in fact it ranks first as an injury- or death-causing accident. This statistic is attributable to bad pedestrian practices mainly and to the lack of proper pedestrian facilities to a lesser degree. The problem of pedestrian accidents is further presented in Table 3, which indicates that pedestrians hit by vehicles constitute about 40 to 45 percent of all casualties. Passengers constitute about 30 to 35 percent and drivers about 25 to 30 percent of all casualties. Bad road user behaviors are observed particularly in the ignorance of priority rules, wrong turning procedures, wrong overtaking, and lack of experience.

Therefore, poor road user behavior can be attributed to several reasons, which may include:

1. Poor understanding of road safety regulations,
2. Insufficient law enforcement, and
3. Insufficient driver training program.

CONCLUSION AND RECOMMENDATIONS

A combination of geometric design elements and road user behaviors are generally considered to be the major causes of road accidents in Jordan. The losses incurred by this problem are believed to be too burdensome for a country of the size of Jordan. Table 4 presents estimated road accident cost through the year 2000. Highway engineering techniques can be implemented to improve geometric design problems. However, in order to prevent human errors, two general approaches can be used:

1. Directly influencing road user behavior through education, training, publicity, and police enforcement, and
2. Using highway and traffic engineering techniques to avoid circumstances in which road users are found to make accident-causing errors.

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Truck Accident Involvement With and Without Front-Axle Brakes: Application for Case-Control Methodology

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Methods of predicting the change in accident involvement of heavy trucks that would result from the mandatory installation of tractor-trailer front-axle brakes were identified. The choice of method for evaluating the front-axle brake issue became controversial as a result of the finding that a system-wide accident and exposure study would be prohibitively expensive and would take longer to complete than the life expectancy of the regulatory decision. The methodology known as "case-control" seemed an attractive alternative, but its previous use for heavy-truck accidents had been severely challenged. The usefulness of this method may have been obscured during a period of rightful questioning of the interpretation of the results from earlier case-control studies. A detailed analysis was made of the statistical limitations and practical feasibility of the case-control methodology. A computer simulation demonstrated that the method can be used to provide unbiased estimates of the coefficients in a logit-type causal accident model, and that only one control per accident is required. Further, it was recommended that rather than focusing on accident-involvement odds ratios, the model from the case-control methodology should be used in a probabilistic economic analysis to answer the regulatory question. Case-control was found to be a suitable approach for evaluating the front brake issue, but only at a level of threshold economic benefit and not in terms of absolute accident rate (number/veh-km). Moreover, it should be implemented only with certain safeguards, notably the validation of the randomness of control vehicle selection using classified vehicle counts. Estimated costs of implementation, although much below those of system-wide inspection surveys of truck exposure and accidents, were nevertheless substantial.

THE PROBLEM OF EVALUATING POTENTIAL TRUCK EQUIPMENT REGULATIONS IN CANADA

A research project required the design of methodology to obtain accident and exposure data for comparisons of heavy trucks with certain configurations and equipment. More specifically, data were needed to produce reliable inferences about the benefits of changes to the Canada Motor Vehicle Safety Standard (CMVSS) 121. Standard CMVSS 121 primarily concerns the airbrake systems of heavy trucks.

A number of changes to CMVSS 121 have been under consideration. These changes include the mandatory installation of front-axle brakes on tractor-trailers, a number of standards applicable to brake performance, and a requirement that front limiting valves, if fitted, be automatic. Although the study did cover a number of other equipment issues, including drive-axle pressure-reducing valves, load-sensing valves, trailer hand-valves, power steering, A- versus B-type trailer hitches, and bobtail configurations, the urgency of the proposed changes to the CMVSS required that most of the methodological effort be devoted to tractor-trailer front-axle brakes.

Any change to the standards must undergo a formal evaluation known as a regulatory impact assessment (RIA). A major part of such studies involves comparing the predicted benefits of a regulation with the costs involved in compliance. In the present context, this assessment implies the use of a fair and statistically competent method of predicting accident-reduction benefits. No such method had been established for an RIA of heavy truck equipment regulations.

Building the statistical case for modifying or leaving intact the CMVSS 121 standard requires the consideration of many technical complexities. It also requires an appreciation of the manner in which amended regulations can reasonably be implemented and enforced, and of the level of proof without which the trucking industry may be reluctant to cooperate. Furthermore, the operation of equipment-specific truck accident and exposure data collection methods would be impossible without the close and sometimes generous cooperation of the trucking industry.

Putting the cost of predicting the benefits of front-brake compliance in perspective, it was estimated that mandatory installation of front brakes on new trucks would only cost about $1.5 million per year spread over 10,000 to 15,000 new vehicle sales. During the current climate of deregulation and increased competition (which one industry representative described as survival time), it was found that most trucking companies would be willing to cooperate in an evaluation, but that it was unlikely that companies would want to participate in experiments in which equipment was randomly installed or proscribed across a fleet.

Thus, the objective for the study was to develop for Transport Canada a solution that is theoretically sound and relevant to the regulatory decisions, and that respects the reasonable interests of the truck manufacturers and end-users. The findings presented resulted from new methodological research; a 2-day technical workshop for a dozen experts from industry, government, and the research community; and interviews of trucking firms, service companies, public authorities, and others

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who would be involved in carrying out an eventual study of accident involvement.

Sources of Methodological Difficulty

Fundamental to the adequacy of accident and exposure data collection methods is the difficulty of identifying the status of the truck at the time of measurement. This problem frequently occurs in driver characteristics—age, sex, training, experience, physical and mental state, and so on. But in vehicle characteristics, there are peculiar difficulties because the identification and verification of the devices can only be done in close and direct cooperation with the owner and operators of the equipment. This cooperation is essential because

- No comprehensive data base of trucks is in operation that will identify truck technology at the level of interest;
- Trucks are modified by the dealer, aftermarket, and operator for some of the equipment identified, and there is even less standardization of records at this level;
- Only the owner or operator controls the level of maintenance. A further difficulty may be that the related equipment is sufficiently poorly maintained, resulting in the equipment of interest being verified to be in good condition, but not being able to do its job; and
- Only the owner or operator controls driver quality. The possibility exists that the equipment has been tampered with, such as in the case of disconnected front brakes. Intentional misuse or nonuse is a further possibility, which in the case of front brakes can effectively eliminate their usefulness in as little as 6 months.

Difficulties are also specific to accident data. Canadian provincial accident data records are limited in their description of trucks involved and categories of truck are not always consistently defined across the country. In general, police accident reports do not contain sufficient detail to eliminate from analysis those accidents that are irrelevant to the equipment issues under study. Other sources of accident follow-up, notably insurance companies and fleet management, can sometimes supply the missing detail, but these are not always available for the vehicles selected for study.

In developing exposure data for the vehicles with the equipment under study, verifying that the vehicles selected are not highly atypical would be desirable. Some overall picture of truck use is needed as a basis for comparison. The purpose is not to estimate the absolute safety impact of equipment so much as to ensure that any judgment about the CMVSS made from accident studies cannot be criticized as irrelevant to typical truck use. The best source at the present time is the *Provincial Truck Fleet Study—1986* (*1*). Unfortunately, neither this nor any other source can provide an independent measure of the use patterns of trucks with precisely the equipment-configuration combinations of interest. Therefore, such sources are mostly useful for the design of sampling strategies.

Timing of the regulatory decision also brings some difficulties. Statistical confidence may be satisfied by tracking accidents for reasonable samples of trucks over an extended period. However, the decision cannot be postponed just to satisfy sampling requirements. After the decision, additional time may be needed before a new or modified standard is implemented to allow the industry to respond to the new requirements. Moreover, the useful lifetime of a standard may be limited because of the evolution of truck technology.

The Distribution of Trucks with Front-Axle Brake Systems in Canada

The size of truck populations containing, or likely to soon contain, the technologies will place an upper limit on the number of trucks and fleets available to potential experimental designs. If the total truck population using the technology is too small for the collection of data within a reasonable length of time, then it may not be feasible to evaluate comparisons of the type with versus without on the basis of relative accident involvement. The percentage of three-axle trucks with front brakes installed is changing rapidly as a result of a U.S. regulation requiring front brakes on all trucks using federally funded highways in the United States, regardless of origin. Because most large Canadian trucking companies operate across the border to some extent, this regulation has resulted in a large increase in front brake installations on new vehicles and in the retrofit market [on the basis of comments from Bendix, Wabco, Eaton-Yale, and original equipment manufacturers (OEMs)]. Currently, the major OEMs are reporting 80 to 95 percent installation rates.

The average frequency of front brakes in use was measured in a 1986 Transport Canada study (*2*), which measured a mean installation rate of 54 percent. This rate was found to vary across Canada—40 percent in Alberta and British Columbia, 50 percent in Saskatchewan and Manitoba, 66 percent in Ontario and Québec, and 50 percent in New Brunswick. Truck replacement rates vary from area to area and on the basis of economic cycles. In the last few years, new truck sales have been strong (up to 12 percent replacement of the fleet per year), but an 8 to 10 percent average replacement rate should be assumed for the near future. On the basis of this range of replacement and front brake installation rates for these new vehicles, Table 1 presents low and high forecasts of the average percentage of the total fleet that will be equipped with front brakes out to 1992. This simple forecast assumes that the replaced vehicle is the average of the vehicle pool. In fact, this assumption will underestimate the total penetration as the older vehicles (i.e., the replacement market) are likely to have less than the average front brake installation. One consequence of U.S. regulation is that trucks without front-axle brakes are increasingly a phenomenon of regional or local trucking companies, limiting the potential for studies based on interfleet comparisons.

A further complexity is the installation of limiter valves (called proportioning or automatic limiting valves in the United States), which proportion or eliminate front brake pressure until preset brake pressures are achieved. Thus, under light braking the front brakes are not activated, but under hard braking the front brakes are applied. This device is intended to decrease front wheel lock-up and skidding under light braking action or load. Moreover, these valves are sold in automatic (U.S. regulations) and manual configurations. According to the OEM industry representatives interviewed, between

TABLE 1 LOW-HIGH ESTIMATES OF FRONT BRAKE PENETRATION IN POPULATION

Installation Rate On New Trucks: 75%/90%
Replacement Rate Of Fleet: 8%/12%

Region	1986 base%	1988 lo%/hi%	1990 lo%/hi%	1992 lo%/hi%
BC/Alberta	40	46/52	50/61	54/68
Saskat/Manitoba	50	54/60	57/67	60/72
Ontario/Québec	66	67/72	69/76	70/79
Maritimes[1]	50	54/60	57/67	70/72
Wt. Average[2]	55	57/62	59/67	61/71

[1] Assumes N.B. data is indicative of entire Maritime Provinces
[2] Weighted by total truck registrations

62 and 100 percent of the front brake systems are currently specified with pressure limiting valves (based on comments from Freightliner, Navistar, Ford, Volvo GM-White, Mack, and Kenilworth).

PREVIOUS SOURCES OF DATA ON LARGE TRUCKS

A number of approaches have been adopted to study large truck accidents and exposure, mostly in the United States. Although it is clear that truck operations in Canada differ in some important respects, the U.S. studies offer some insights into the methodological and practical difficulties involved under North American conditions. The most important of the sources reviewed were

- Truck Inventory and Use Survey (TIUS) (*3*);
- Fleet Accident Evaluation of U.S. FMVSS 121 (*4*);
- University of Michigan Transportation Research Institute Large-Truck Survey Program, including the Trucks Involved in Fatal Accidents (TIFA) data base, 1980 to 1984, and the National Truck Trip Information Survey (NTTIS), 1985, University of Michigan (*5*);
- Truck Case-Matching Survey, 1984–1985, Insurance Institute for Highway Safety (IIHS) (*6*);
- Consolidated Freightways Single and Double Trailer Accident Study, 1978, John C. Glennon Chartered (unpublished data);
- Study of the safety experience of large trucks in Saskatchewan (*7*);
- Ontario's Commercial Accident Study Program, 1979–1981, Ministry of Transportation, Ontario (MTO) (unpublished data); and
- New York State Economic and Safety Consequences of Increased Truck Weight, 1987, Cornell University (J. Richardson, unpublished data).

Each study involved an ambitious amount of data collection, sometimes at considerable cost. For example, the two recent UMTRI data bases—NTTIS and TIFA—together have cost about $1 million. Because only the IIHS and MTO studies involved physical inspection, the level of information about installed equipment is, in general, of insufficient detail for present purposes.

A major additional concern is the size and duration of studies that would be necessary to track differences in accident rate attributable to equipment differences. On the basis of NTTIS and TIFA, an approximation of the level of truck use that might need to be monitored can be obtained to find sufficient accidents to start making such comparisons. For example, the overall accident rate for tractor combinations in the United States is about 240 police-reported accidents per 100 million km. These 240 accidents consist of approximately 155 property damage only, 80 injury, and perhaps four or five fatal involvements. If the trucks monitored averaged 100,000 km/year, one would have to monitor 1,000 trucks to expect 240 accidents. However, although trucks carrying general freight in the United States average close to 160,000 km/year, the overall average for tractors is about half, or 80,000 km, meaning that about 1,250 randomly selected U.S. trucks would have to be monitored to obtain those 240 accidents. If the notion of case and control groups whose rates are to be compared is now introduced, it is easy to demonstrate that only large differences in rates could be detected with samples of a reasonable size over reasonable periods of time.

Important new insights into truck accident rates have been obtained from the studies reviewed. However, the studies also illustrate that the possibilities of developing methodologies to compare absolute accident rates are daunting in the case of rarely found equipment configurations, especially if their contribution to accident reduction turns out to be marginal.

CHOICE OF METHODOLOGY FOR THE FRONT-AXLE BRAKE ISSUE

Consensus on Constraints

Substantial discussion has occurred about whether the collection of system-wide exposure data should be mandated. Much of the debate focuses on the interpretation of the results from the case-control methodology by IIHS, which had been used to avoid a mandate in the state of Washington. In particular, results on relative accident involvement by various factors such as truck configuration seemed to differ markedly from similar comparisons from the UMTRI studies. Although there were no results of direct relevance to the equipment-configuration comparisons of interest in the current study, the same disparity could be expected in those areas as well.

A wide range of practical constraints on data collection in Canada were considered. Of major importance was the emergence of the commercial vehicle safety (CVSA) inspection capability in all provinces. It was generally seen as workable and appropriate for CVSA personnel, without police support, to stop and inspect trucks for control purposes. Serious reservations about fleet-based studies were expressed because of the high likelihood of selection bias. This view was not a criticism of the industry because selection bias can arise from fleet characteristics, such as the purchase of certain types of equipment for use with specialized loads or operations. A related matter was the possible disproportionate importance of small trucking operations with a wide diversity of man-

agement practices and other variations from equipment standards.

In focusing on the development on tractor-trailer front-axle brakes, it was agreed that any methodology must involve physical inspection of trucks in use. It was noted that power steering and limiting valves interact with front-axle brakes and therefore must be taken into account along with other factors, notably brake condition and adjustment, which can be verified only through physical inspection. However, it was recognized that a methodology involving physical inspection randomly distributed across the whole highway system would be likely to cost more than the implementation of the regulation itself.

Thus, the methodological work was constrained to answering the major unresolved issue previously discussed—explaining the discrepancy between the relative accident involvement of differently equipped trucks, as previously estimated from system-wide studies, and those using case-control methods to collect data only at accident sites. In practical terms, this limitation meant developing a recommendation as to which of three candidate solutions was the most efficient at meeting the needs of the RIA on front-axle brakes—a fleet-matching study, a case-control study at accident sites, or a case-control study in which the exposure of controls is validated against data from vehicle inspections carried out randomly across the road system.

The Rejected Options

Option I: Fleet Matching Studies (Inter or Intra), with Tracking of Accident Rates

On the basis of further discussions with the trucking industry, fleet following studies did not emerge as a viable alternative. In order to obtain statistically sound estimates of the benefits of mandating front-axle brakes within a time frame appropriate for the regulatory decision, it would be necessary to find a large number of trucks of similar vintage whose front-axle brake status could be established with certainty and guaranteed to be held constant, or at least subject to accurate tracking of changes in status during an extended period of data collection. Because this would involve checks on the installation of front-axle brakes and associated equipment, maintenance, and possible driver readjustment this task was seen as essentially impractical. In addition, many aspects of tracking and record keeping for such vehicles would be likely to interfere to some degree with trucking operations, perhaps even resulting in changes to the duty cycles of case and control vehicles. This option is potentially far more disruptive to the industry than various forms of random inspection on public roads, which would be necessary under the alternatives.

Option II: Case-Control Study with Controls Drawn Network-Wide

Exploration of this solution consumed a considerable amount of effort but was ultimately rejected, not because it was undesirable, but because it was a less efficient method of answering the regulatory issue than the option selected. This stage of the methodological work included extensive discussions between statistical and data experts at Transport Canada, the consultant team, and the IIHS about the limitations of case-control methods.

The discrepancy between case-control and system-wide exposure surveys was found to be a question of weighting. In other words, if system-wide estimates of relative risk or accident rates are needed, it would be necessary to augment a case-control study with the random selection of controls across the system. However, in order to achieve these data in sufficient detail to weight all the equipment-configuration comparisons of interest for their system-wide exposure, large-scale sample surveys would be required that would be more elaborate than the multimillion dollar data collection efforts of UMTRI. In this case, the solution would amount to doing both a case-control study at the accident sites and the type of overall system exposure survey for many different cells of the truck population, which was rejected as too ambitious for RIA purposes alone.

System-wide truck accident rates are valuable; however, for the limited purpose of addressing the regulatory decision a less costly solution, which allowed a test of minimum economic benefit, was essential.

Option III: The Recommended Option, a Case-Control Study at Accident Sites

Therefore there were few alternatives to the case-control approach in which controls are matched to accidents at the accident sites. However, the use proposed for such a case-control approach is that of testing whether a front-axle brake regulation would pass a threshold of economic benefit.

The key conclusions about the case-control method can be stated in terms of limitations on the interpretation of results. Most of Transport Canada's concerns about the method related to the limited nature of the sample obtained when accident-involved trucks and matched controls are selected only at the accident sites, as is proposed here, and as was done in the IIHS-Washington state study. After addressing numerous examples, it was clear that such limited sampling could not be used to obtain truck accident and exposure rates for the road system as a whole, which can be restated as the corollary to the conclusion under Option II with regard to system-wide measurement of controls: The case-control method, confined to accident sites, is not capable of developing population estimates of the prevalence of no front brakes as a cause of accidents over the whole road system, nor can such a method provide accident rates per vehicle-kilometer (with or without front brakes).

Use of the case-control methodology at the accident sites makes possible the calculation of the relative odds that two subclasses of trucks distinguished by the absence or presence of front-axle brakes will be involved in an accident at those sites. Such odds have a particular statistical definition as coefficients in a logit-type regression model. Findings in this form for factors other than brakes have been published in road safety studies. However, as an article (*6*) on the IIHS-Washington state study points out, relative odds are not comparable to rates that take into account how much each subclass of trucks is used on the road system as a whole. Unfortunately,

results expressed as relative odds have been misinterpreted by some readers as absolute measures of performance in the system.

In the RIA context, the study proposed a limited objective for case-control at the accident sites, such that the interpretation of results is unambiguous. Rather than the publication of relative risk statistics, the proposed use of relative odds is to predict a change in accident frequency for the class of accidents sampled. This prediction would be achieved by using a regression model in which the coefficients have been changed to simulate the effect of universal fitment of front-axle brakes.

The principle is simple—to collect inspection data at accident sites in Canada and to estimate how many fewer or more accidents would likely occur with front-axle brakes installed on all tractors passing those sites. If a reduction in accidents is estimated and if that reduction expressed in dollar savings is sufficiently large to offset the costs of compliance with a universal front-axle brake standard, then the needs of the RIA would be satisfied.

For purposes of evaluating whether a regulation would have sufficient impact, the class of accidents sampled could be a major subset, rather than all heavy-truck accidents. For example, the analysis could apply to all road types, but a subset of accidents defined by road class might be sufficient for RIA purposes, provided that countervailing effects could not logically be expected on road types not sampled.

Enhancements to the case-control procedures, as used previously, are essential if the method is to be used in connection with an RIA on the front-axle brake regulation.

A Statistical Introduction to Case-Control Methodology

Case-control methodologies have previously been applied in many medical research studies and in a limited number of applications in road safety research, including studies of pedestrian and truck accident causation. The basis of the case-control method is that a case (i.e., an observation of an item with the effect's under investigation being present) is first observed and then another observation is made on a control (i.e., a similar item but without the effect's under investigation being present). The only things allowed to vary between the case and control are those factors being specifically studied for their influence on the presence of the effect.

For example, consider a medical study in which the effect of smoking on the incidence of lung disease is to be studied. The first step would be to identify a sample of persons suffering from lung disease and then to record a number of characteristics for the people in this sample that are thought to be related to lung disease. The next step is to find people without lung disease who match the individuals in the sample with respect to all (or most) characteristics except for their smoking behavior. If successful in matching people on the basis of all the characteristics except smoking behavior, then a simple comparison of the proportion of smokers in the lung disease sample with the proportion of smokers in the non-lung-disease control sample will provide an estimate of the odds ratio for the effect of smoking on lung disease. If smoking does cause lung disease, then the odds ratio should be significantly greater than unity.

The same procedure can be applied to truck accidents and the effect of installing front brakes on the incidence of accidents. In this case, the first step would be to identify a sample of trucks involved in accidents and then to record a number of characteristics for the trucks in this sample that are thought to be related to the incidence of accidents. The next step is to find trucks not involved in accidents that match the trucks in the sample with respect to all (or most) characteristics except for installed front brakes. If successful in matching trucks on the basis of all the characteristics, except installed front brakes, then a simple comparison of the proportion of trucks with front brakes in the accident sample with the proportion of trucks with front brakes in the nonaccident control sample will provide an estimate of the odds ratio for the effect of installation of front brakes on accidents. If installation of front brakes does reduce accidents, then the odds ratio should be significantly less than unity.

Unfortunately, it is rarely possible to have such a closely matched control sample as described because normally more characteristics vary between the case and control sample than just the variable under study. In such situations, it is necessary to control for these other variables by means other than matching. The usual way to do this is to construct a multivariate statistical model of the accident causation process and by statistical inference estimate the likely contributory effects of each of the variables that has not been matched between the case and control samples.

In the truck accident analysis, it is assumed that the cases and controls are matched on the basis of site and time (month of year, day of week, and time of day) by selecting the control observations from the same road as the accident at the same time of day 1 week after the accident. Calculation of the odds ratios is based on the assumption that even though the case and controls are matched with respect to site and time the accident causation process is still a multivariate process. The accident is caused not only by the presence or absence of front brakes, but also by various design features, driver characteristics, and management factors (in addition to various other unspecified factors). Therefore, it is not sufficient to simply calculate naive odds ratios from the raw data but rather it is necessary to estimate a multivariate model of accident causation. The model most often used in this respect is the multivariate logistic regression [or multinomial logit] model. This model is similar in format to that used in many models of transportation demand, such as mode, route, and location choice. The basic format of the model is

$$p\{x\} = 1/\{1 + \exp[-(b_0 + b_1x_1 + \ldots + b_nx_n)]\} \quad (1)$$

where

$p\{x\}$ = probability of an accident's occurring given the set of variables $\{x\}$,
$\{x\}$ = $\{x_1, x_2, \ldots, x_n\}$,
b_i = parameter that estimates the effect of variable x_i on the probability of an accident, and
b_0 = constant that accounts for the effects of variables that are not specified in the model.

In this simple model, only four types of variables, namely, front brakes (x_f), vehicle design features (x_v), driver characteristics (x_d), and management factors (x_m), can be reexpressed in the logit model.

$$p = 1/\{1 + \exp[-(b_0 + b_f x_f + b_v x_v + b_d x_d + b_m x_m)]\} \quad (2)$$

Rearrangement of the logit model results in the following format

$$\ln[p/(1 - p)] = b_0 + b_f x_f + b_v x_v + b_d x_d + b_m x_m \quad (3)$$

This form is similar to a conventional multiple regression model except that the dependent variable is the log of the odds (often termed logits). The transformation of the dependent variable is necessary to bound the probability to lie between zero and one and gives the familiar sigmoid curve for the logit regression model.

The b parameters in the logit model can be shown (*8*, p. 233) to be the logarithms of the multivariate odds ratios for each variable (assuming that the variable is dichotomous).

Although the logit model was initially formulated in the context of a cohort study (one in which elements in the population are observed over time to see whether a symptom appears, i.e., to see whether a control becomes a case), Schlesselman (*8*) observes that the method is just as appropriate in a case-control and a matched case-control study with the only difference being in the magnitude and interpretation of the constant term b_0. The interpretation of the b_i coefficients remains the same in each case.

With matched analysis of matched case-control data, each pair of data points is allowed to have an individual value of b_0 (whereas in unmatched case-control the value of b_0 remains the same over all data points). However, the values of b_i are the same as those obtained from unmatched case-control data.

It is also possible to perform unmatched analysis on matched case-control data (i.e., collect the data in a matched fashion, but perform the analysis as if the data were unmatched). Under these circumstances, two outcomes are possible with respect to the values of b_i. First, if the cases and controls have been matched on a variable that is associated with the study exposure then the estimates of the b_i values will be biased towards unity. On the other hand, if the matching is based on a variable that was not associated with the exposure, then the unmatched analysis would not bias the estimates of b_i and would, in fact, increase the precision of the b_i estimates. In the current study, it would appear that the matching variables (site and time) are unlikely to be strongly associated with the study exposure variable (the presence or absence of front brakes) and hence an unmatched analysis of the matched data would appear to be justifiable.

The estimation of the b_i coefficients is performed using maximum likelihood estimation (MLE) methods, with the usual tests of significance associated with MLE (such as likelihood ratio tests) being appropriate. As with all regression models, it is possible to enter transformations and interactions between independent variables into the model by means of specific transformations (e.g., powers of terms) and by multiplication of the independent variables to form a new variable.

In order to provide a secondary means of calculating the sampling error associated with the estimation of the b_i coefficients, it is possible to use replication methods. The simplest way is to randomly divide the cases into two independent samples and then perform the logit model estimation independently for each sample. Variance in the parameter estimates obtained from the two samples can be used as confirmation of the parameter variances estimated as part of the MLE estimation procedure.

The Need To Augment the Case-Control Method Previously Used for Truck Studies

In identifying enhancements to the case-control procedures, the point of reference was again the most relevant previous study, the IIHS-Washington state study. The objective has been to build on IIHS's experience, rather than to criticize their approach. With IIHS's cooperation, it has been possible to identify ways to make the results of a case-control study easier to validate and therefore more credible in an RIA context.

Establish a Population of Accidents Suitable to the Regulatory Context, such that Comparably Defined and Disaggregated Secondary Data are Readily Available from Police Accident Records

Unlike the IIHS study, which looked at a wide range of accident causation issues, a logic is needed to establish a sampling frame appropriate to the relatively narrow regulatory context. This requirement implies that sampling will not only respect technical requirements, but will also lend credibility to the RIA when it is subjected to political scrutiny.

The objective is to predict a change in accident frequency for a class of heavy-truck accidents that may be sufficient to offset the costs of a front brake regulation. This decision must initially take into account the researcher's judgment about the credibility of a result based, as was previously suggested, on a subset of accidents. There are two important dimensions to this.

First, can a regulation be justified if the cost can be shown to be offset by predicted accident savings on only that part of the system that has been measured? Could a result be defended, for example, only on the basis of a sample of fatal heavy truck accidents on freeways if enough potential savings can be shown there alone to pay for the costs of a regulation? If the answer is yes, it is essential to consider if there is any logic for a substantial reversal of results on any class of heavy truck accidents that have not been covered in the study. For example, will someone argue that front brakes are useful on freeways but a hazard on winding roads not built to freeway standards?

A related matter is the need for the sampling design to take into account the potential for costing the accidents. It might, for example, be efficient to stratify on accident severity to oversample injury accidents, which have higher average costs than property damage accidents.

No matter what the choice of sampling frame may be, it should be recognized that the method of matching controls to accidents is impractical in locations with low truck traffic volumes and some part of the system will inevitably be excluded. A strong case can also be made for excluding accidents on urban roads, other than freeways. Accidents on these roads

tend to be of lower severity. For example, in Ontario urban areas in 1986, 34 percent of accidents involving a heavy truck as the striking vehicle were classified as fatal or injury accidents. This figure compares to 38 percent for freeways and ramps and 46 percent for primary rural undivided roads (Transport Canada, unpublished data). Moreover, the logistics of investigating trucks on urban streets are daunting. Fortunately, it is difficult to imagine a logic that suggests that front-axle brakes are likely to lead to any sort of driving difficulty in urban areas and so the exclusion of urban accidents is unlikely to weaken an RIA that justifies a regulation based on a study of rural roads.

The second dimension involves asking if it is acceptable to extrapolate from a limited data set to a broader but supposedly equivalent situation. The most obvious example would be to justify the regulation by showing that the accident savings on a particular subset of accidents in only one or two provinces is enough to offset the costs of the regulation to the truck fleets in those same provinces and then to assume that the same holds true for the rest of Canada. Case-control methodology cannot be used to describe anything about classes of accidents not included in the sampling frame, but one may wish to assume that the same result would be obtained if the same sampling frame was used in a wider geographical area. Substantial survey cost and operational advantages are obtained by making such an assumption.

The specification of which accidents are to be considered cases must take into account the level of detail in police accident records because the extrapolation will involve calculating a hypothetical change in accident frequency from a baseline that is provided by police records for the total population. The baseline must be available using accident classifications and a level of disaggregation that are comparable to those used for selecting case accidents in the study. For example, it is not possible to extrapolate findings from a case-control study confined to tractor-trailers on limited-access highways if police data lack road class and truck type as accident descriptors. In some types of surveys, it is possible to use sample data to estimate the size of the population when an independent source is unavailable or incomplete. The manner in which the sample is drawn in the present study will not permit such an approach.

For the Selection of Control Vehicles, Set Up a Method of Obtaining Classified Traffic Count Data at the Control Site, to Ensure that the Selection of Control Vehicles is Truly Random

Certain additional conditions that were not met are needed for the selection of control trucks in the IIHS-Washington state study. Most important is that a classified traffic count be taken at the time that control trucks are selected and examined. The objective of this count is to ensure that the controls are representative of the total fleet passing the accident sites, at least with respect to observable characteristics. The selection of control trucks by inspectors is always open to the criticism of conscious or unconscious selection bias. For example, it might be that inspectors will tend to do what they are normally required to do—select vehicles in apparently questionable condition. It might be equally true that for the extra inspections carried out as part of a study some inspectors might select trucks that can be inspected quickly, incurring less objection from the drivers whose trips are interrupted. This selection bias could extend to a tendency to choose or avoid vehicles of certain trucking companies, possibly introducing a selection bias on some nonvisible characteristic that differs by company. If this problem is suspected, and certain companies have sufficient presence in the accident site area, the trucking company could be observed as a count variable.

Even if this count significantly increases the labor cost of the method, it is essential to address perhaps the most serious shortcoming of case-control methodology as it has been applied in the past. Costs may be minimized by using a video camera to record passing traffic. Even if selection bias is shown to have occurred, by comparing the control vehicles to the classified traffic count data obtained at the control sites, the count data could be used to weight the control data so that the composition of the sample of controls matches the composition of the classified counts.

Use Trace-Back Procedures for Accident-Involved and Control Trucks

Procedures may be added to trace accident-involved and control trucks back to their operating companies to include fleet management factors in the study. Trace-back procedures relate in particular to the question of maintenance and company policies regarding front-axle brakes.

Augment the Analysis of Case-Control Data

Finally, a number of methods are suggested to improve the analysis of data and to estimate the potential impact of the regulation. These methods include performing a secondary estimate of sampling error using replicates and the use of Monte Carlo methods to provide a distribution of accident reductions, which can then be used in a probabilistic economic analysis. These enhancements were subjected to a pilot test in the form of a computer simulation.

Cost and Feasibility of a Case-Control Study of Front-Axle Brakes in Canada

Field requirements and costs of a case-control study of front-axle brakes in Canada were verified in a series of interviews with provincial highway departments, police authorities, trucking companies, and the parties involved in the IIHS-Washington state study—IIHS and the Washington State Commercial Vehicle Inspection Division. Richardson and Campbell (*9*) discuss data collection requirements; experience from previous studies involving roadside truck inspections; the roles of the police, the investigation team, and the provincial vehicle inspectors; and the potential response of contracted mechanic teams.

Such a case-control study would be feasible in Canada, but the costs would be high. A spreadsheet model was developed that could be used to examine, interactively, various decisions

about acceptable statistical error, the expected impact of the regulation, and the number of field teams desired. Two examples of output from the model using the outer limits of reasonable assumptions estimated the likely cost in a range of $700,000 to $2,750,000 for studies capable of detecting 40 or 15 percent reductions, respectively, in accidents attributable to the regulation. Almost all of the difference between these estimates resulted from the large increase in cases necessary to detect the smaller reduction—from 383 to 2,314, respectively. Use of provincial vehicle inspectors rather than contracted mechanic teams could reduce these estimates by 6 to 10 percent.

A COMPUTER SIMULATION TO TEST FOR BIAS IN THE CASE-CONTROL METHOD

Approach

One of the nagging questions about the case-control methodology is whether the method will provide reliable and unbiased estimates of the odds ratios given that the sample is biased toward accidents and away from the majority of miles traveled without an accident. Put simply, how can one expect to get good estimates of the risk associated with various design features when the data consist of some accidents and a couple of observations that have been matched to each accident?

Although Schlesselman (*8*) and Manski and Lerman (*10*) noted that the variable coefficients obtained from a case-control or choice-based sample are reliable and unbiased estimates of those that would be obtained from a full random sample, it was felt desirable to empirically demonstrate the validity of this claim in the context of a case-control accident study. Therefore, the purpose of this analysis was to test the application of case-control methodology to the estimation of reductions in truck accidents following the implementation of a vehicle design feature such as the installation of front brakes.

The analysis was based on a simulation modeling method, wherein a population of accidents was first generated on the basis of an assumed causal model of accident causation. Controls were then selected and the MLE method used to reestimate the underlying (known) causal model. The degree to which the original model coefficients could be reestimated from the simulated data set and the sensitivity of the estimated coefficients to the number of controls selected per accident were primary considerations in assessing the viability of the case-control method for estimating causal accident models.

Because of the nature of simulation, repeated applications of this technique would generate numerically different (but statistically similar) data sets. Therefore, the model coefficients estimated by MLE would not necessarily agree exactly with those of the original model. However, repeated application of the simulation model would generate a distribution of model coefficients and these distributions should not be significantly different from the original model coefficients (if the premise is correct). In addition, if the case-control method yields the same results as from a full random sample, then the results should be independent of the number of controls observed per case (with a full random sample simply being a large number of controls per case).

Stages in the Simulation

Stage 1

For the purpose of this simulation, a simple causal model was assumed in which the probability of an accident depended on only two independent variables (viz., the presence or absence of front brakes and the age of the vehicle). One of these variables is discrete whereas the other is continuous. In a more comprehensive analysis, other variables, such as the age of the driver, the number of hours the driver had been driving at the time of the accident, the size of the company operating the truck, the type of road, and the time of day, could be included in the causal model. It was postulated that the probability of an accident's occurring to any particular truck passing a site on the road network is given by the following logit model:

$$p = 1/\{1 + \exp[-(b_0 + b_f X_f + b_v X_v)]\} \quad (4)$$

where

p = probability of an accident's occurring,
b_i = coefficient associated with the variables X_i,
X_f = dichotomous variable for the presence of front brakes, and
X_v = vehicle age in years.

Stage 2

Coefficients were then selected with plausible signs and with magnitudes such that reasonable estimates of probabilities and changes in probabilities were obtained. A total sample size of approximately 200 accidents was seen as being a feasible and realistic objective. On the basis of these considerations and on the total population of site-time combinations described, the following coefficients were adopted: $b_0 = -7.2$, $b_f = -0.295$, and $b_v = 0.023$.

Stage 3

A population of sites was then constructed on an assumed road network with a relatively realistic composition of road type, geometry, and time of day. For example, it was assumed that there were 500 locations, with 200 divided and 300 undivided sites. For divided road sites, it was assumed that 30 percent of these sites were on curves, whereas for undivided road sites it was assumed that 50 percent were on curves. For each site, 12 hr of daytime flows and 12 hr of night time flows were later generated. These assumptions yielded a total of 12,000 site-time combinations.

Stage 4

At each site-time combination, total hourly truck flows were generated. Time-of-day flow profile was assumed such that between 1 and 8 percent of the day's traffic was observed in each 1-hr period of the day. On divided roads, an average daily flow of 1,000 veh/day was assumed, whereas on undi-

vided roads, an average daily flow of 200 veh/day was assumed. A normal distribution of flows with a coefficient of variation equal to 20 percent of the mean for divided road sites and 30 percent of the mean for undivided road sites was assumed. From these distributions, an expected hourly flowrate was generated for each of the 12,000 site-time combinations.

Stage 5

For each hourly flow, average parameters were generated for each of the other variables. Average percentage of trucks with front brakes was set to 60 percent, but the average age of the vehicle was set to be higher on undivided roads (10 years during the day and 11 years at night) than on divided roads (8 years during the day and 7 years at night). It was assumed, for simplicity, that all variables are independently and normally distributed with a coefficient of variation equal to 20 percent of the mean value.

Stage 6

For all the 12,000 site-time combinations, a program was written to set up a simulated data matrix for the variables road type, geometry, time, flow, percent with brakes, and vehicle age.

Stage 7

For the first site-time combination, the characteristics of each of the vehicles (trucks) passing that site were generated using the normal distribution and coefficient of variation equal to 40 percent of the mean.

Stage 8

For each truck passing the site, the probability of an accident was calculated using the causal model and coefficients specified in the initial stage. Then, applying Monte Carlo techniques, a uniform random deviate (between 0 and 1) was generated for each truck. Whether or not an accident occurred was determined by comparing the random deviate with the probability of an accident. If the random deviate was smaller than the probability, then an accident was deemed to have occurred. If an accident occurred at this site-time combination, then the details of this accident vehicle were saved in a separate accident matrix.

Stage 9

For each accident included in the sample at this site-time combination, a set of three control vehicles passing that site was generated (as outlined in Stage 7). The population from which these controls were selected corresponds to the flow of vehicles that would have passed the same site 1 week after the accident. The details of these control vehicles were also saved in the accident data matrix. Simulation Stages 7, 8, and 9 were then repeated for all 12,000 site-time combinations.

Stage 10

At the end of this procedure, the simulated accident data set now represented the information that would have been obtained had a real case-control survey been conducted. With these data, it was now possible to estimate the accident causation logit model and reestimate the coefficients using MLE.

On completion of Stages 1 to 10, the estimated model was compared with the known causal model developed in Stages 1 and 2. More important, it was also possible to determine whether the estimated model coefficients were affected by the number of controls selected, and hence, by logical extension whether the case-control method itself was able to generate data that provided a means of estimating unbiased coefficients for the accident causation model on the basis of a full random sample of truck travel exposure.

At this point in the analysis, had this been a real study, the next stage would have been to estimate changes in accident probabilities. However, for regulatory purposes the change in the number of accidents would be calculated and the net economic benefits would be estimated. In order to do this, the simulation was extended to demonstrate an approach in three final stages.

Stage 11

For each observation (of either a case or a control) in the sample, the front brakes variable was changed to reflect installation of front brakes on the entire fleet by changing all occurrences of a zero for the front brakes variable (X_f) to a value of one. The probability of an accident's occurring under these conditions was then calculated by application of the accident causation model estimated in Stages 1 through 10.

Stage 12

Given the new probabilities of accident occurrence for each observation, the occurrence of an accident under existing and projected conditions was then simulated using the Monte Carlo technique described in Stage 8. Number of accidents was then summed for existing and projected conditions, and the difference in these summations was an estimate of the reduction in the number of accidents in this sample brought about by the installation of front brakes. The repetition of this stage with a different set of random numbers would result in a different estimate in the number of accidents saved by the installation of front brakes. A full analysis would require the estimation of a distribution in the number of accidents saved, expressed as range of outcomes. (For example, in the imaginary sample of 200 accidents, the average reduction in accidents over 100 runs of the simulation was 11.41, with a standard deviation of 3.52).

Stage 13

The change in the number of accidents could then be assigned an economic value (based on standard accident costs) and compared with the cost of retrofitting front brakes to the fleet to determine the economic viability of the retrofit policy.

TABLE 2 COEFFICIENTS DERIVED FROM THE SIMULATION

	Coefficient	S.E.
Average B_0	-0.826	0.222
Average B_1	-0.372	0.179
Average B_2	0.005	0.023

Results of the Analysis

As a result of the simulation, a data set of approximately 800 observations (200 accidents and 600 controls) was generated. This data set was then read into a data file using the SYSTAT statistical package on an Apple Macintosh personal computer. The nonlinear regression module of SYSTAT was then used to obtain MLE of the coefficients in the logit model of accident causation.

The output from the analysis is a set of coefficients and accompanying standard errors for the underlying logit model. This analysis was repeated four times with independent data sets to obtain an empirical estimate of the variability of the estimated coefficients. The results of the analysis are presented in Table 2.

Average values for the coefficients B_1 and B_2 (for front brakes and vehicle age, respectively) are not in total agreement with the expected values of -0.295 and 0.023. However, their signs are correct and they are within one standard error of the expected value. Therefore, it cannot be rejected that the case-control method and the MLE did in fact succeed in reestimating the coefficients in the underlying causal model. The constant term (-0.0826) was not close to the constant term in the underlying model (-7.2), but this discrepancy was to be expected because of the higher proportion of accidents in the case-control data set than in the total population of site-time combinations. Naturally, the estimated coefficients could be made more precise by use of a larger data set, particularly one containing more accidents. However, in the current study, the data set was limited by the capabilities of the statistical package in use.

Although the direct comparison of estimated and expected coefficients gives some indication that the case-control methodology gives unbiased estimates of the coefficients, a further test would involve experimenting with the number of controls. In this study, the number of controls was reduced to two and then one by progressively eliminating one or two controls per case from the existing data sets generated in the four runs. For the two-control situation, the third control was eliminated from each case, whereas for the one-control situation both the second and third controls were eliminated. Model coefficients were then estimated with the results presented in Table 3.

Table 3 indicates that as the number of controls is decreased, coefficients B_1 and B_2 fluctuate, but this fluctuation is not systematic. On the other hand, the constant term becomes more positive as the number of controls is decreased.

The fluctuation in B_1 and B_2 may be caused by two sources—either the number of the controls per se, or the composition of the total sample after removal of the controls. Although all the data sets (within one run) are based on the same total set of three controls per accident, the manner in which the controls are removed creates the possibility of creating essentially different data sets when the controls are removed. In order to overcome this possibility, the analysis for the fourth run was redone but with the controls being removed in a systematic fashion. Thus, three two-control data sets were built by removing, in turn, the first, second, and third control in each case. Similarly, three one-control data sets were constructed by including only the first, second, and third controls in each case. In this way, the average of the two-control cases more closely represents the three-control case (because each control is represented a total of two times in the three data sets), whereas in the one-control case each control is represented a total of one time in the three data sets. The results of this analysis are presented in Table 4.

The change in the number of controls has absolutely no effect on the estimation of the coefficients B_1 and B_2, whereas the constant term B_0 becomes more positive as the number of controls decreases. This finding is consistent with the findings from other areas of transportation research, such as mode choice modeling, in which it has been found that a logit model that is calibrated on a choice-based sample (equivalent to the case-control methodology) will provide unbiased estimators for all coefficients except the alternative-specific constants

TABLE 3 THE EFFECT OF REMOVING ONE, THEN TWO CONTROLS

	Three Controls		*Two Controls*		*One Control*	
	Coefficient	S.E.	Coefficient	S.E.	Coefficient	S.E.
Average B_0	-0.826	0.222	-0.605	0.233	0.219	0.257
Average B_1	-0.372	0.179	-0.309	0.181	-0.405	0.249
Average B_2	0.005	0.023	0.008	0.025	0.001	0.027

TABLE 4 AVERAGED COEFFICIENTS AFTER SYSTEMATIC REMOVAL OF CONTROLS

Run #4	*Three Controls*		*Two Controls*		*One Control*	
	Coefficient	S.E.	Coefficient	S.E.	Coefficient	S.E.
Average B_0	-1.061	0.266	-0.654	0.256	0.041	0.283
Average B_1	-0.219	0.255	-0.219	0.201	-0.219	0.294
Average B_2	0.011	0.022	0.011	0.030	0.011	0.011

(*10*) and that the constant can be corrected by means of a factor relating the market share in the full sample to the market share in the choice-based sample.

Conclusions from the Simulation

Implications of the simulation study previously described include

1. Case-control methodology can provide data to obtain unbiased estimates of the coefficients in a causal accident model of the logit type, which will be the same as those estimated from a full random sample of travel exposure;
2. The precision of these estimates will be affected by the total sample size. Because of the complexity in the sampling and estimation procedures, it is recommended that replication methods be used to empirically estimate the variances of the estimated coefficients; and
3. A simulation method can be used on the total sample of cases and controls to estimate the reduction in accident numbers resulting from the installation of front brakes to all trucks in the sample. Monte Carlo methods provide a distribution of accident reductions, which can then be used in a probabilistic economic analysis.

CONCLUSION

This study focused on identifying ways of predicting the change in accident involvement of heavy trucks that would result from the mandatory installation of tractor-trailer front-axle brakes. Initially, it was hoped that any data collection necessary for such predictions would also yield, as a by-product, some broad measures of system safety relevant to trucking operations. Early in the study, it became apparent that such a by-product would be prohibitively expensive and the study was directed toward identifying the most efficient approach to evaluating the regulation without measuring accident rates on the system as a whole.

As a result, the methodology proposed has been developed to answer only this limited question—will the benefits of a proposed mandatory front-axle brake regulation be likely to outweigh the costs entailed? After extensive checking, it was concluded that a modified application of the methodology known as case-control provides the most efficient method of answering that question.

Use of case-control methodology in road safety evaluation has generated considerable controversy in recent years. However, the usefulness of the method has been somewhat obscured during a period of rightful questioning of the interpretations, by some readers, of the results from earlier case-control studies.

This study is not intended to rekindle the controversy. Much of the debate has, unfortunately, hung up on the meaning of the relative involvement ratios that are derived as coefficients in a logistic regression. In the context of equipment regulation, methodology is much more useful if these coefficients are not treated as end results, but rather are used to predict changes in accident frequencies under defined sets of conditions.

That choice-based samples and logit models work in this application is not surprising. The problem is not unlike some of those in travel demand modeling that have long been using such methods. However, the strength of the previous controversy compels a restatement that this methodology is not a potential source of system-wide heavy-truck accident rates. In particular, it should be noted that the methodology is not designed to yield accident rates per vehicle-kilometer for trucks with different equipment configurations.

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PART 2

Studies on Enforcement, EMS, Safety Management, and Simulation

Public Opinion Regarding Photo Radar

Mark Freedman, Allan F. Williams, and Adrian K. Lund

Photo radar is an automated speed surveillance system that photographs speeding vehicles, drivers, and license plate numbers so that citations can be sent by mail. A telephone survey was conducted among residents of two communities (Paradise Valley, Arizona, and Pasadena, California) where photo radar is being used; residents of nearby communities were also surveyed. Considerable awareness of the use of photo radar was found, especially in Paradise Valley, where 72 percent of the people surveyed mentioned it spontaneously. In all areas, 58 percent either approved or strongly approved its use; residents of Paradise Valley and Pasadena were more likely to approve than residents of nearby communities. Two-thirds of those who approved of photo radar thought its use should be increased. Almost half of the respondents who knew that photo radar was being used said that they were driving more slowly as a result.

Photo radar is a speed enforcement tool that has been used in about 40 countries during the last 15 to 20 years. A photo radar unit consists of a narrow-beam, low-powered Doppler radar speed sensor aimed across the road, a motor-driven camera and flash unit, and a computer. The portable unit detects, photographs, and records information on every vehicle that passes a particular roadway location while exceeding a certain speed. The photographs show the vehicle, its license plate number, and the operator. The photographic information enables the police to issue a citation for speeding to the vehicle's owner. The vehicle owner is normally held responsible for the citation. In the United States, photo radar has been used in a way that allows the citation to be transferred to the driver if the owner was not driving the vehicle.

Photo radar offers a number of advantages over conventional speed enforcement techniques. Photo radar can positively identify speeding vehicles in a nondiscriminatory fashion, producing photographic evidence that also provides the speed, time, date, location, and other relevant information. The equipment can detect and record nearly all speeders, photographing successive vehicles as close as 0.5 sec apart, while providing safeguards that ensure that the speed measurements will be associated with the correct vehicle. Photo radar emits a relatively low-powered microwave signal (in the gigahertz range) and is effective against vehicles with radar detectors. Because police do not need to pursue and stop offenders, hazardous exposure of police officers, speeders, other vehicles, and pedestrians is reduced. The resulting high level of speed enforcement could otherwise be achieved only by assigning several police officers and vehicles to each enforcement site. Consequently, officers are available for other tasks.

The photo radar operator may elect to measure speeds of both oncoming and receding vehicles simultaneously or separately. For receding vehicles, passenger cars and trucks can be distinguished using the radar to also measure vehicle length. Consequently, a different speed limit can be selected for each of the two vehicle types.

Several techniques are used to prevent errors in photographing vehicles or issuing citations when there is doubt about the vehicle in question. In one system, if two vehicles moving at different speeds are simultaneously within the limits of the radar beam, the computer stops the speed measurement and the camera is not triggered. In another system, if the computer determines through rapid repeated sampling that the measured speed is not correct or cannot be assigned to a specific vehicle, the measurement is stopped. The computer precisely controls the timing of a photograph so that the image of the target vehicle is always within a specific area of the photograph. If more than one vehicle is in the photograph, a template can be used to identify the target vehicle.

Photo radar is an efficient way to identify speeding drivers, and the initial evidence of its effects on speeds and crashes is promising. On the West German autobahn between Frankfurt and Cologne, photo radar was installed to help increase compliance with a 100-km/hr speed limit imposed to reduce the annual average of 300 crashes that resulted in 80 injuries and 7 deaths. Compliance with the new speed limit was poor before photo radar was used; photo radar recorded 63,000 violations during 1978, and the safety record improved to 9 crashes, 5 injuries, and no deaths (*1*).

The police department of Paradise Valley, Arizona, reported substantially fewer crashes in the year after the implementation of photo radar. An early form of photographic identification of speeding vehicles, known as ORBIS III, was tested in Arlington, Texas, over a 3-month period in 1976. This system was found to decrease the proportion of speeders on major urban roads by one-half or less with no enforcement (*2*).

Because photo radar combines several recent technologies in a novel manner, the American public has had relatively little experience with it as a law enforcement tool. Several legislative, judicial, and community acceptance issues surround the use of photo radar. In many jurisdictions, specific legislation may be required before photo radar can be used. Legal issues of due process concerning photo radar, such as whether mailing a ticket is permissible and whether an owner (not the driver) can be held liable for the ticket, have not yet been resolved. In addition, public knowledge about and acceptance of photo radar are important considerations regarding its use.

Photo radar is being used in Paradise Valley, Arizona, and Pasadena, California. Paradise Valley is a small community ($17\ mi^2$, with a population about 12,000) adjacent to Phoenix. One photo radar unit has been used there since September

Insurance Institute for Highway Safety, 1005 N. Glebe Road, Arlington, Va. 22201.

1987. The unit is currently deployed about 30 hr per week, distributed among several locations on both residential and arterial streets. Pasadena, a suburb of Los Angeles, is a slightly larger and more densely populated community (23 mi^2, with a population about 130,000) than Paradise Valley. A photo radar unit has been operated in Pasadena since June 1988 for approximately 15 to 25 hr per week. In Paradise Valley, signs posted at the entrances to the community advise that photo radar is used for speed enforcement, and a sign saying "photo radar ahead" is placed upstream from the unit, giving motorists an opportunity to slow down before they reach it. In Pasadena, 75 signs saying "Speed enforced with photo radar" are posted throughout the city, and a sign saying "You have just passed through photo radar" is placed just downstream of the unit. In both cities, photo radar is deployed in vehicles prominently displaying local police markings.

To determine public attitudes about and acceptance of photo radar, a telephone survey of drivers residing in and around these communities was conducted. The surrounding communities were surveyed because of the possibility that drivers living in those areas had exposure to photo radar but different opinions of it than residents of Paradise Valley or Pasadena.

PHOTO RADAR OPERATING CHARACTERISTICS

Photo radar combines a narrow-beam (about 5 degrees horizontal, between 5 and 22 degrees vertical) Doppler effect radar system with a still-frame, motor driven camera and flash unit, which are controlled by a small computer. The system is aimed across the road (rather than up or down the road like conventional speed radar) at an angle of about 20 degrees from the road edge. The speed of each vehicle that enters the radar beam is measured and compared to the speed limit that has been entered into the computer. When the radar unit sends a signal to the computer that a vehicle has exceeded the speed limit, the computer directs the camera (and flash if necessary) to photograph the vehicle. The photograph records the vehicle's appearance, license plate number, driver's face (for frontal views), vehicle speed (from information relayed by the computer), date, time, and other system and location details. The camera's motor drive then advances the film to the next frame. System recycle time ranges from 0.5 sec (without flash) to 3 sec for full flash power.

The radar transmitters operate in the gigahertz (GHz) microwave range; one manufacturer uses 13.45 GHz and another uses 34.3 GHz. Transmitter power output ranges from 0.5 milliwatts (mW) for one system to 10.0 mW for another. Because the radar frequencies are substantially different from those used by police radar in the United States (either 10.525 or 24.150 GHz), and the beam is narrow, low-power, and directed across the road, photo radar is not effectively detected by radar detectors. The systems can measure speeds in the range of 15 to 150 mph or more, with an error range of plus or minus 1 to 3 mph for speeds under 100 mph and plus or minus 1 to 3 percent for higher speeds.

METHODS

Interviews for the survey were conducted by telephone from August 18 through September 5, 1989, by Opinion Research Corporation. Random-digit dialing methods were used to select households. In each household, one interview of a licensed driver was conducted.

Approximately equal numbers of interviews were conducted with residents of Paradise Valley (501 interviews) and nearby areas (Phoenix and Scottsdale, 500 interviews), and residents of Pasadena (502 interviews) and nearby areas (Glendale, Burbank, South Pasadena, Alhambra, San Gabriel, Temple City, Arcadia, El Monte, Monrovia, Altadena, San Marino, La Canada, La Crescenta, Sierra Madre, and Duarte, California; 502 interviews). The maximum expected sampling error at the 95-percent confidence level for each study area is ± 4 percentage points. Differences of 6 percentage points or more between areas are statistically significant at $p \leq 0.05$.

TABLE 1 AWARENESS OF PHOTO RADAR BEING USED

	Paradise Valley %	(N)	Near Paradise Valley %	(N)	Pasadena %	(N)	Near Pasadena %	(N)
Mentioned Spontaneously	72	(363)	39	(197)	56	(283)	24	(122)
Knew when Prompted	24	(119)	47	(235)	34	(170)	51	(255)
Not aware of	4	(19)	14	(68)	9	(46)	25	(124)
Not Sure	0	(0)	0	(0)	1	(3)	0	(1)
Total	100	(501)	100	(500)	100	(502)	100	(502)

Question: What kinds of techniques do the police use to enforce speed limits where you drive?

The interview required about 10 min to complete. Respondents were asked questions in three areas: awareness of photo radar, attitudes toward its use, and reported behavior in response to photo radar.

SURVEY RESULTS

Awareness of Photo Radar

Respondents were first asked to indicate techniques used by the police to enforce speed limits in areas where they drive. Then a description of photo radar was read to them: "During the last year a new speed enforcement tool known as photo radar has been used in Paradise Valley (or Pasadena). It automatically photographs the license plate and the driver of only those vehicles traveling significantly faster than the speed limit." Respondents who had not already mentioned photo radar spontaneously were then asked if they had known it was being used.

Table 1 indicates that there was considerable awareness of the use of photo radar in Paradise Valley and Pasadena. Awareness of photo radar was greatest among residents of Paradise Valley, where 72 percent of the respondents mentioned it spontaneously, followed by Pasadena residents (56 percent). More respondents living near Paradise Valley mentioned it spontaneously (39 percent) than those living near Pasadena (24 percent). In all four areas surveyed, the great majority of respondents either mentioned photo radar spontaneously or claimed to know about its use after it was described to them.

Most of the respondents said that they drive in or through Paradise Valley or Pasadena at least occasionally (Paradise Valley, 99 percent; near Paradise Valley, 91 percent; Pasadena, 98 percent; near Pasadena, 90 percent). The majority of people who drive through Paradise Valley or Pasadena and had heard of photo radar said that they had seen photo radar in use (Table 2). Residents of Paradise Valley (89 percent) or nearby communities (75 percent) were more likely than residents of Pasadena (64 percent) or nearby communities (52 percent) to say they had seen it. Including all respondents in the denominator, the percentages claiming to have seen photo radar in use were as follows: Paradise Valley, 84 percent; near Paradise Valley, 61; Pasadena, 57; near Pasadena, 36.

Table 3 presents the percentage of respondents (5 percent or less) who said they had received a speeding ticket because of photo radar.

Attitudes Toward Photo Radar

Overall, 58 percent of the respondents either approved or strongly approved of the use of photo radar, 37 percent disapproved or strongly disapproved, and 5 percent were not sure (Table 4). Paradise Valley and Pasadena respondents (both 62 percent) were most likely to approve of photo radar. Overall, the proportion of those who strongly disapproved of photo radar was the same as the proportion of those who strongly approved (15 percent).

Of those approving of photo radar, 67 percent said they thought its use should be increased (Table 5). In each of the four areas surveyed, about two-thirds of the supporters of photo radar thought its use should be increased.

Table 6 presents the major reasons that people disapproved of photo radar. These reasons were not read to respondents but were listed on the survey form and circled if mentioned. In addition to the five reasons for disapproval listed in Table 6, some respondents also said: "photo radar represents 'big brotherism' in government" (8 percent); "waste of taxpayers' money" (6 percent); "rather be pulled over; should be personal contact" (3 percent); and "illegal, entrapment, unconstitutional" (2 percent).

Response to Photo Radar

Tables 7–9 are based on the responses of drivers who had heard of photo radar and who drive through Paradise Valley

TABLE 2 RESPONDENTS WHO HAD SEEN PHOTO RADAR IN USE

Seen In Use	Paradise Valley %	Paradise Valley (N)	Near Paradise Valley %	Near Paradise Valley (N)	Pasadena %	Pasadena (N)	Near Pasadena %	Near Pasadena (N)
Yes	89	(423)	75	(307)	64	(287)	52	(182)
No	11	(50)	23	(92)	34	(152)	45	(160)
Not Sure	1	(3)	2	(8)	2	(11)	3	(11)
Total	101	(476)	100	(407)	100	(450)	100	(353)

Question: Have you ever seen or driven past a photo radar unit being used in Paradise Valley/Pasadena?

Note: Data based on those who have heard of photo radar being used and who drive through Paradise Valley/Pasadena.

TABLE 3 SPEEDING TICKETS OR WARNINGS IN PAST 3 YEARS

Speeding Tickets or Warnings	Paradise Valley %	(N)	Near Paradise Valley %	(N)	Pasadena %	(N)	Near Pasadena %	(N)
Yes - photo radar	5	(25)	3	(15)	3	(13)	2	(12)
Yes - not photo radar	22	(112)	22	(110)	17	(86)	16	(81)
No	73	(364)	75	(375)	80	(403)	81	(409)
Total	100	(501)	100	(500)	100	(502)	99	(502)

Question: Have you received a speeding ticket or warning in the last three years? Was the ticket issued by the photo radar system?

TABLE 4 ATTITUDE TOWARD USE OF PHOTO RADAR

Attitude	Paradise Valley %	(N)	Near Paradise Valley %	(N)	Pasadena %	(N)	Near Pasadena %	(N)
Strongly approve	20	(101)	12	(60)	16	(82)	12	(58)
Approve	42	(212)	37	(185)	45	(227)	47	(234)
Disapprove	23	(114)	26	(131)	23	(113)	20	(99)
Strongly disapprove	12	(62)	20	(99)	12	(59)	15	(74)
Not sure	2	(12)	5	(25)	4	(21)	7	(37)
Total	99	(501)	100	(500)	100	(502)	101	(502)

Question: Do you approve or disapprove of photo radar? Would you say you approve, strongly approve, disapprove, or strongly disapprove?

TABLE 5 ATTITUDE TOWARD INCREASED USE OF PHOTO RADAR

Photo Radar Should Be Used More Than It is Now	Paradise Valley %	(N)	Near Paradise Valley %	(N)	Pasadena %	(N)	Near Pasadena %	(N)
Agree	70	(226)	63	(169)	64	(212)	69	(228)
Disagree	24	(77)	22	(59)	22	(72)	12	(38)
Not Sure	7	(22)	16	(42)	14	(46)	19	(63)
Total	101	(325)	101	(270)	100	(330)	100	(329)

Question: Do you think photo radar should be used more than it is now?

Note: Data based on those who approve or strongly approve of the use of photo radar.

TABLE 6 MAIN REASONS FOR DISAPPROVING OF PHOTO RADAR

	Percent who say yes			
Reason	**Paradise Valley**	**Near Paradise Valley**	**Pasadena**	**Near Pasadena**
The wrong person can get ticket/errors will be made	38	43	35	32
Gives Police unfair advantage: is sneaky	39	28	31	39
Violates right to privacy	28	16	29	27
Does not give driver chance to tell his/her side of story	17	23	11	12
Does not slow people down, not effective/does not work	16	12	14	11

Question: Why don't you approve of photo radar?

Note: Data based on those who disapprove or strongly disapprove of the use of photo radar; respondents could give one or more reasons.

TABLE 7 REPORTED DRIVING BEHAVIOR WHEN IN PARADISE VALLEY OR PASADENA

	Paradise Valley		Near Paradise Valley		Pasadena		Near Pasadena	
Behavior	**%**	**(N)**	**%**	**(N)**	**%**	**(N)**	**%**	**(N)**
Drive slower	56	(268)	50	(202)	39	(176)	42	(148)
Do not drive slower	42	(202)	49	(201)	60	(268)	56	(196)
Not sure	1	(6)	1	(4)	1	(6)	3	(9)
Total	99	(476)	100	(407)	100	(450)	101	(353)

Question: Has photo radar made you drive slower when you drive through Paradise Valley/Pasadena?

Note: Data based on those who have heard of photo radar being used and who drive through Paradise Valley/Pasadena.

or Pasadena. Table 7 indicates that many respondents (47 percent overall) say that photo radar has made them drive more slowly through Paradise Valley or Pasadena. Those living in or near Paradise Valley were more likely to report driving more slowly than those living in or near Pasadena.

In each of the four areas surveyed, the majority who reported driving more slowly said that they did so wherever they were in Paradise Valley or Pasadena (Table 8). The remainder said they drive more slowly where they think photo radar might be used (22 percent overall), where they see photo radar in use (19 percent), or where they were not sure (2 percent). About one quarter said that photo radar had also made them drive more slowly outside Paradise Valley and Pasadena.

Table 9 indicates that people were more likely to say that photo radar had made them drive more slowly if they had mentioned photo radar use spontaneously when asked about speed enforcement techniques, if they had seen photo radar in use, and if they had received a speeding ticket—especially a photo radar ticket—in the last 3 years.

DISCUSSION OF RESULTS

In the two U.S. communities where photo radar is being used, there is considerable awareness of its presence. This is especially so for Pasadena and Paradise Valley residents but is also true among people in nearby communities, and many say they have seen it in use, even though photo radar is not used extensively in either community. There was greater familiarity with photo radar in Paradise Valley than in Pasadena, presumably because Paradise Valley is a smaller community and because it has been used there longer and more frequently.

TABLE 8 WHERE AND WHEN RESPONDENTS SAY THEY DRIVE MORE SLOWLY

Where/When	Paradise Valley %	(N)	Near Paradise Valley %	(N)	Pasadena %	(N)	Near Pasadena %	(N)
In Paradise Valley/Pasadena								
All the time	60	(162)	53	(107)	56	(98)	57	(84)
Where they think photo radar might be used	24	(63)	26	(53)	19	(34)	17	(25)
Where they see photo radar being used	13	(36)	20	(40)	23	(40)	25	(37)
Do not know/not sure	3	(7)	1	(2)	2	(4)	1	(2)
Outside Paradise Valley/Pasadena								
Yes	28	(74)	20	(41)	27	(48)	25	(37)
No	70	(188)	77	(155)	70	(124)	73	(108)
Do not know	2	(6)	3	(6)	2	(4)	2	(3)

Question: When driving in Paradise Valley/Pasadena do you drive slower: All the time; where you think photo radar might be used, or just where you see photo radar being used?

Question: Has photo radar made you drive slower outside of Paradise Valley/Pasadena?

TABLE 9 REPORTED SLOWER DRIVING IN RELATION TO AWARENESS OF PHOTO RADAR

	Percent Driving Slower			
Awareness of/ Encounters	Paradise Valley	Near Paradise Valley	Pasadena	Near Pasadena
Mentioned photo radar spontaneously	60	55	40	49
Had heard of when prompted	45	45	37	39
Have seen photo radar in use	59	55	46	53
Have not seen photo radar in use	34	33	29	31
Photo radar ticket	72	71	54	78
Other speeding ticket	66	57	49	47
No speeding ticket	52	46	36	40

Many people, especially those with the greatest familiarity with the photo radar system, say they drive slower because of it. The majority of those who reported driving more slowly said they do so whenever they are in that community, not just where they see photo radar or think it might be, and a minority said they drive more slowly outside these communities as well. People often misrepresent their actual behavior in surveys, and research needs to be conducted to determine the effect of photo radar on actual speeds where the system is used and at other locations. Nevertheless, the survey suggests that some people change their behavior because of photo radar.

There is considerable support for the use of photo radar, especially by residents of communities that are using it, but a large minority of people disapprove of its use. The most popular reason for disapproval is the possibility of errors and the wrong person getting a ticket. However, virtually the only error this system generates occurs when the owner of the vehicle was not the driver. The owner still receives the ticket, but the photographic evidence allows the owner to show that he or she was not the driver. Otherwise, there is little possibility of error. The second most popular reason for disapproval was that it is "sneaky" and gives police an "unfair advantage." However, as noted previously, signs are used widely in both cities to warn drivers that photo radar is in use. Photo radar does eliminate interaction at the scene between police and driver that would allow the driver to explain mitigating circumstances, but it is objective, accurate, and nondiscriminatory.

The evidence from this survey suggests that photo radar can be an effective speed enforcement tool and that a majority of the people who live in areas where photo radar has been used favors its use.

ACKNOWLEDGMENT

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Public Attitudes Toward Traffic Regulation, Compliance, and Enforcement in Urban Areas of the United Kingdom

PETER M. JONES

Public attitudes toward traffic regulation, compliance, and enforcement in urban areas of the United Kingdom were examined in a study for the U.K. Department of Transport, through a series of group discussions among road users and a national quantitative survey. Most drivers admitted to breaking at least some types of traffic regulation, and drivers and nondrivers generally agreed on which were the most serious offenses—usually those with a perceived safety or congestion impact. Twelve factors were identified that affected compliance levels in urban areas: physical ease of offending, quality of the traffic signs, existence of exemptions for certain groups, perceived rationale behind the regulation, persons adversely affected by noncompliance, convenience of legal alternatives, enforcement level and penalty, magnitude of the infringement, importance of the trip, compliance by others, personal predisposition, and familiarity with the area. People have a sense of territory in their local area and may ignore traffic regulations that are felt to be there to control through-traffic. Despite the common use of personal judgment about when to comply, virtually everyone accepted the need for traffic regulation and wanted better enforcement of certain offenses, such as dangerous driving and illegal parking; where the latter caused congestion or a safety hazard, there was also strong support for towing away the offending vehicle. Better understanding of which regulations people regard as reasonable and why should make it possible to increase compliance levels without additional enforcement resources.

The movement of traffic in urban areas is governed by a wide range of regulations intended to control the use of vehicles and ensure the smooth, safe, and orderly flow of traffic. In Great Britain, many of these controls are introduced under the Road Traffic Regulation Act 1984, which empowers highway authorities to make traffic regulation orders (TROs) to regulate the speed, movement, and parking of vehicles, and to regulate pedestrian movement. In most cases, this policy means that in Britain, unlike many other countries such as the United States, any contraventions are made against the legal TRO, not the traffic sign or road marking that notifies its existence to the traveler. The content and scope of a TRO can vary greatly and may be quite complex. Thus, regulations can be closely adapted to meet local needs, but enforcement problems can arise because of the difficulty of correctly and fully signing a TRO (often not all exemptions are shown, for example).

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OBJECTIVES AND METHODS

The work reported here was one of a series of studies commissioned by the U.K. Department of Transport into various aspects of the traffic regulation and parking control arrangements available to local authorities under the Road Traffic Regulation Act 1984. The objective of this research was to obtain "a comprehensive series of insights into the public understanding of the role of traffic regulations and parking control techniques which surround the management of road users, particularly in urban areas."

The study concentrated on six main types of regulation:

- Waiting and loading restrictions,
- Parking controls,
- Access restrictions,
- Carriageway reservations (e.g., bus lanes),
- Pedestrian facilities, and
- Restrictions on movements at junctions.

The following topics were covered in the surveys of public attitudes:

- Local and general traffic problems in urban areas;
- Problems faced by specific groups of road users, and in different types of areas;
- Public awareness of the TRO notification and consultation procedures;
- Familiarity with and comprehension of TRO notices;
- Awareness and comprehension of signing, and suggestions for improvement;
- Reported noncompliance with selected types of traffic regulation, by specific groups of road users;
- Perceived seriousness of infringements of different traffic regulations;
- Public views on the enforcement of urban traffic regulations: deterrence, detection, and penalties;
- Support for different types of traffic management policy giving priority to particular road-user groups, including pedestrians, cyclists, and bus passengers;
- Resolution of the conflicting demands for curb space; and
- The need for traffic restraint in urban areas.

Public views on these issues were sought in two ways. The first method was a series of intensive group discussions lasting two to three hours, during which respondents discussed each

of these issues in turn under the guidance of an experienced interviewer, using a range of visual aids to focus discussion (videos, color slides, newspaper cuttings, and leaflets). Twenty-one group discussions were carried out in five different-sized urban areas in England, selected to reflect different traffic problems and a variety of traffic measures. Approximately 150 people took part in the discussions. The second source of public attitudes was a national, household-based quantitative survey covering a random sample of 2,126 adults living in Great Britain; the questions were derived from hypotheses that came out of the discussion groups.

The national survey provided a broad indication of public attitudes across the country as a whole, whereas the qualitative interviews provided an opportunity to probe attitudes and behavior in much greater depth, and to seek explanations for the observed regularities. The analysis drew on approximately 4,000 pages of national data analysis and 800 pages of transcripts from over 50 hr of taped discussion.

The following road users were represented in the surveys:

- Pedestrians,
- Pedal cyclists,
- Bus passengers,
- Car passengers,
- Handicapped drivers,
- Professional drivers, and
- Private motorists (ranging from occasional to frequent drivers).

The following affected land users were represented in the surveys:

- Local residents,
- Shopkeepers, and
- Local business people.

In addition, the professional opinions of a number of local authority engineers and police officers were sought in the study areas. The main intention of the study, however, was to seek out the views of individual members of the public.

Two aspects of this wide-ranging study—public compliance and views on enforcement of traffic regulations—are covered here. A brief summary (*1*) of the full study and the published version of the full report (*2*) are also available. Although there were differences in view among and between population subgroups and the various study areas, in most cases the findings were fairly consistent, with evidence of a high level of consensus in the public mind.

ATTITUDES TOWARD COMPLIANCE WITH TRAFFIC REGULATIONS

Approximately half of the drivers in the national survey were asked about the extent to which they might ignore certain types of traffic regulation on some occasions; the other half of the drivers, and the nondrivers, were asked how seriously they viewed infringements by others. Ten types of infringement were described, representing a range of moving and stationary vehicle offenses. For each situation, motorists were asked to identify with one of the following statements:

1. I would never knowingly do that—I think it's wrong.
2. I know I shouldn't do that, but I might—just occasionally.
3. I do that when I think I can get away without being caught.
4. I often do that—I think it's a stupid regulation.

In order to counter a possible reluctance to admit to traffic offenses, the introduction stressed that most people bend the rules occasionally, and in several cases the examples referred to minor infringements (for example, ignoring a short section of No Entry). The proportion of drivers who agreed with statements 1 and 2 for each offense is presented in Table 1. Table 2 presents the answers to the questions on the seriousness of these offenses (rated on a five-point scale from That is a very serious offense to That should not be an offense).

In most cases, drivers and nondrivers agreed on the relative seriousness of infringing different TROs, and a reasonably clear relationship emerged between the likelihood of compliance and perceived seriousness. Four of the 10 offenses were consistently seen as being very serious, and drivers rarely admitted to ignoring these regulations. These regulations were

1. Parking in a bus lane when it is in operation,
2. Ignoring a short No Entry section of road,
3. Ignoring a No Right Turn when quiet, and
4. Stopping briefly on a white zigzag line (marked on the curb on approaches to a pedestrian crossing, where vehicles are not allowed to stop or overtake other vehicles, to ensure clear sight lines).

Speeding was somewhat anomalous. Most drivers admitted to doing 40 mph at a quiet time in a 30-mph area at least occasionally. Only 18 percent of the drivers viewed this offense as very serious, but twice as many nondrivers took this view. Speeding was the only regulation of those tested showing a divergence of views between drivers and nondrivers. A smaller divergence of view was evident in the case of pavement parking—drivers saw this as the only option in some narrow roads, whereas nondrivers were more aware of the hazard it could cause to blind pedestrians or people walking with push chairs or in wheelchairs.

Few sociodemographic differences in attitude among the population were observed for the offenses perceived to be very serious. For offenses generally regarded as less important or serious, however, men were more willing than women to report that they broke the regulations themselves and regarded infringement by others as less serious. Younger people more often responded "more likely to ignore" and "less serious offense" than older ones, and people who drove for a living were particularly prone to breaking these regulations and to regard infringement as less serious than the average motorist. Cyclists admitted to ignoring many regulations, although they reported that they would usually comply with them if they were driving.

A comparison of views held by the same individual about the general adequacy of enforcement and amount of regulation to the perceived seriousness of different violations resulted in the following conclusions:

- Drivers who wanted more enforcement were most likely to regard offenses as very serious, and

TABLE 1 REPORTED NONCOMPLIANCE BY DRIVERS

SITUATION*	OWN BEHAVIOUR Never	Occasionally
Ignore short 'No Entry'	82%	10%
Park in bus lane	82%	10%
Stop briefly on white zig zag line(1)	81%	13%
Ignore 'No Right Turn' when quiet	80%	9%
Drive in bus lane	73%	21%
Park in Residents' spaces	49%	29%
Park on pavement where road narrow(2)	49%	35%
Ignore local access restriction	45%	36%
Park on single yellow during the day(3)	38%	38%
Doing 40mph in 30mph area when quiet	23%	48%

*Note: examples used are often 'minor' infringements

Explanation of infringements:

(1) An area marked out along the kerb on the approaches to a pedestrian crossing where vehicles are not allowed to stop or overtake other vehicles (for safety reasons, to ensure clear sight lines).

(2) It is generally illegal in the U.K. to park a motor vehicle on a footway - although in some cases this is permitted (and signed); not all respondents realised that pavement parking is illegal.

(3) It is an offence to park along a stretch of kerb with a single yellow line during the working day, although drivers may set down and pick up passengers and trucks may load/unload there.

• Drivers who thought there were too many regulations viewed noncompliance least seriously.

Among nondrivers, however, there was no consistent association between the two sets of attitudes.

FACTORS AFFECTING COMPLIANCE

Twelve factors that seemed to affect the decision of whether or not to comply with a particular regulation were identified. An overall ranking of the factors could not be established, because their relative importance seemed to be site- and person-specific, and they could be combined in various ways to influence behavior in different situations. Thus, no order of importance is intended.

Physical Restraint or Impedance

• Physical obstacles (barriers, posts, or width restrictions) largely prevented abuse, although some examples of the removal of obstacles were found. Some people liked physical barriers, because they removed the element of choice.

• Often a slight physical impediment (e.g., special curbing at the entrance to a limited-access street), coupled with appropriate signing, may reinforce the sense of wrongdoing and reduce noncompliance: "That would put me off, because the actual road finishes and turns away and it's cobbled after that. That is more of a deterrent than just signs."

• The physical layout of a street—if it looks or feels wrong to be there—may inhibit noncompliance, without any physical restrictions. This layout is referred to as "subliminal signing."

TABLE 2 PERCEIVED SERIOUSNESS OF INFRINGEMENTS BY DRIVERS AND NONDRIVERS

SITUATION	% WHO SAID 'VERY SERIOUS' Driver	Non-driver
Ignore short 'No Entry'	47%	47%
Park in bus lane	50%	49%
Stop briefly on white zig zag	54%	46%
Ignore 'No Right Turn' when quiet	52%	48%
Drive in bus lane	30%	33%
Park in Residents' spaces	17%	15%
Park on pavement where road narrow	32%	40%
Park on single yellow during day	15%	17%
Doing 40mph in 30mph area when quiet	18%	35%
Illegal use of an Orange Badge*	38%	44%

*[A permit issued to a Registered Disabled Person, enabling them to park in a restricted area for a limited period - currently a maximum of 2 hours]

Visibility and Comprehensibility of Signs and Markings

- Some people were more inclined to ignore a regulation if the sign or marking was faded: "Very often the singles (yellow lines) are so dirty anyway, that you're never sure if there is a line there or not. I always plead ignorance with a traffic warden."
- Signs and controls that are obviously temporary were seen by some as less important, and so were more likely to be ignored: "I think people tend to say that temporary traffic lights (used at road works) are not real lights."
- People appeared to be genuinely confused over the meaning or status of some signs; thus, some people might break regulations unintentionally.
- Poor siting or ambiguous wording increased the likelihood of noncompliance, even where people understand the meaning.

Exemptions to the Regulations

- Some people felt it was acceptable to stop briefly on yellow lines, because trucks and buses can do so and they are much bigger and more likely to cause congestion or be a safety hazard.
- Exemptions for buses at a restricted turn also seemed to justify noncompliance; some people argued that if it was safe for a large bus to make a turn, then it must be safe for a small car.

The Rationale Behind the Regulation

The rationale was very important to respondents: Why is it there? Four kinds of rationales were recognized:

- Safety reasons,
- To avoid or reduce congestion,
- To improve the local environment, and
- Other policy reasons (e.g., to discourage car use).

These four objectives were accorded different degrees of acceptance. Regulations with an obvious safety function were highly respected, whereas those introduced for environmental or policy reasons were more likely to be abused. In cases where the rationale was not obvious, providing this information seemed to affect attitudes toward compliance, but only in cases where people supported the objective.

A No Right Turn policy on a main road was challenged by one lady, who often encouraged her husband to ignore the sign because: "I couldn't see what was the point, with the road perfectly clear. Why can't I turn there? I can see right up the road in both directions." One person who was very strongly opposed to anyone parking illegally on yellow lines had one exception—a residential area that he visited frequently and knew well. Double yellow lines had been installed when the road was a major short cut through a residential area (banning parking at all times), but they were retained when it was blocked off: "Double yellow lines in a cul-de-sac, which has got no purpose whatsoever! So everyone ignores those. I put that down as an aberration. . . . I always park on that one and I don't consider it to be an offense—it shouldn't be there."

Who Would Suffer If a Regulation Were Ignored

"You only break regulations if you believe that you're not going to cause any harm." Respondents were more likely to observe a parking restriction, for example, if they perceived that the space was needed by a high-priority user, such as a doctor or a handicapped person.

Availability and Convenience of Legal Alternatives

Justifications were given for the following situations where legal alternatives were not convenient or available:

- Ignoring a banned right turn: "If it meant that you had to go out of your way . . . then you would [ignore it]."
- Ignoring a No Entry sign: "We've got a friend who lives on ________ Road, and he lives on the first house on the right (100 yards up from the sign). So, if nothing's coming, I'll just nip in . . . the road is dead straight . . . otherwise I'd have to drive all the way round the road system and it would take me an extra 10 minutes."
- Pavement parking: "I know a lot of people who live in narrow roads, and I'm in a quandary. What do I do? Do I park on the pavement or do I go off miles and miles away and have to walk back?"

Enforcement Level and Penalty

The more likely people felt it was that an offense would be detected and the more severe the penalty, the less likely respondents were to break the regulation. People would sometimes take action to reduce the risk of detection; examples were given of ways to avoid being caught when parking illegally. "I wouldn't park on a yellow line on the main road; the one I park on in ________ is round the corner," or "You can get away with more with the van. I was outside the bank the other day to pick up some curtains. There was nowhere to park so I left the van outside the bank."

Even where people are not supportive of a regulation, the risk of detection can act as an effective deterrent: "I look after my license with all these things. . . . Although I think the bus lane is stupid, I don't go in it." The only instance where the threat of a penalty seemed to have little effect on behavior was illegal parking by business people: "One of the saddest things in London today is that, for the [representatives] it's just part of the job. Some companies allow [them] up to £100 a week just for parking tickets. They just say there's no way you can park in London."

Short Infringements

People often seemed to adopt the attitude that infringements short in time or space don't count; they are perceived to be less serious, and the chances of being caught are seen to be low. About three-quarters of the respondents in the national survey said they never drive in a bus lane. But most participants in the group discussions acknowledged that they might pull into a bus lane briefly to bypass a car turning right (and so avoid holding up traffic behind) or to avoid oncoming traffic. Such minor violations were not regarded as an offense. Brief parking violations were also justified: "I'd like to know who can put their hand on their heart and say they haven't parked illegally at some point for 5 minutes."

Necessity or Urgency of the Trip or Action

There was considerable sympathy for some groups of people who break certain regulations in order to carry out their job efficiently, such as postmen, milkmen, and delivery drivers: "Where else can he stop but by blocking the traffic which is behind? I have every sympathy with him. I certainly don't sympathize with someone who stops on double yellow lines for just a few minutes." Private motorists admitted to being more likely to ignore regulations if they were in a hurry and when doing so would save valuable time. "It may depend if you've got to get a train, or whatever."

Personal Familiarity With an Area

Many respondents admitted to being less likely to comply with regulations in their own neighborhood, or in an area they knew well and with which they identified. Several reasons were given for this:

- They knew the area and the traffic situation well enough to make a personal judgment about the relevance and effectiveness of the scheme: "I think that's just a stupid system which they've put in there. . . . To me, they've achieved nothing from doing it."
- In some sense, if a scheme is designed to protect local people from through traffic, then access restrictions or banned turns should not apply to locals: "If you know the area as your patch you tend to think of these rules as a bit of a bloody cheek, really."
- Local people are more likely to know what is to be gained by ignoring, for instance, an access restriction: "If you live in the area and you know you can get out of the other end, then you probably would drive through. But if you're a stranger to the area you probably wouldn't go down there."
- A habit pattern predating the regulations may govern behavior: "It's funny because I do it there [ignore an entry prohibition except for access on a short section of road] but I wouldn't do it anywhere else. . . . I used to walk down there to school years ago."
- Knowledge that the regulation is widely abused and poorly enforced increased the social acceptability of noncompliance and reduced the risk of detection: "If someone lives in the area and they've done a maneuver loads of times and seen everybody else do it, it doesn't matter what the sign says—they will do it."
- If the respondent were stopped by a warden or police officer, he would probably know the area well enough to find some plausible excuse for being there.

Perceived Level of Compliance by Others

A perceived lack of compliance by others can lead to a herd effect:

- A taxi driver using an ordinary car said, "You can guarantee if I am in a bus lane (legally), within seconds there is two or three cars behind me."
- "If everyone else was parked on the curb, then I'd park on the curb."

Personal Attitudes Toward Compliance

Some respondents claimed to be more law-abiding than others, although most admitted that there was one type of regulation

they might transgress, or a particular situation in which they occasionally ignored a regulation. In many instances, both motorists and fellow cyclists complained about cyclists ignoring regulations.

GENERAL VIEWS ON TRAFFIC REGULATION AND ENFORCEMENT

Virtually everyone in the national survey accepted the need for traffic regulation and enforcement in urban areas; around half agreed with statements saying that more should be done (either better enforcement or more regulation) and only 6 percent supported the proposition that vehicles and pedestrians are too regulated and fewer, rather than more, controls are needed. In London, 70 percent wanted additional action.

When people who opted for greater enforcement or regulation were asked what they had in mind, 30 percent of the comments in the national survey concerned parking controls and nearly as many related to bad driving (such as speeding, drunk driving, and jumping red lights). The main traffic problems identified in urban areas were road congestion and shortage of parking spaces, which in turn were felt to lead to secondary problems such as speeding, "rat running" (taking short cuts through residential areas), and pavement parking. Even though most drivers admitted to breaking some regulations at least occasionally, there was general support for an increase in enforcement of certain moving and stationary vehicle regulations, especially if the illegal behavior was thought to be dangerous or cause congestion. Enforcement levels and penalties were identified as one of a set of factors influencing compliance; enforcement is particularly important where some of the other psychological restraints do not apply: "I think you respect the zigzags because you know they could cause an accident. I think the yellow stripes [lines] you respect because you feel the weight in your pocket." (See Table 1 for definitions of the markings.)

The use of physical measures to control or prevent abuse (e.g., posts to stop pavement parking) held widespread support, and most motorists showed little resentment at being prevented from behaving illegally. "There's a general air of anarchy around at present, and I think the only solution is to design things so that people can't take liberties. It's sad when you've got to do that." However, opinions differed in the specific cases of speed bumps and barriers across the road. People were generally in favor of using cameras at traffic lights and similar devices to detect the more serious forms of abuse.

Respondents generally believed that, where it is impractical to install a physical measure, the best way of stopping drivers from breaking rules is to increase the resources devoted to detection, which principally means more traffic wardens or traffic police. Despite the bad image that wardens appear to have a respondent commented, "We all curse traffic wardens. I think they're wonderful people, because as soon as they go off duty at 4:30 p.m. you suddenly see cars dumped all over the place, because they know no one is going to give them a ticket." A recent national survey (*3*) found that 75 percent of adults agreed with the proposition that "Traffic wardens do a necessary and worthwhile job."

PENALTIES FOR PARKING INFRINGEMENTS

Different penalties were generally believed to be appropriate for different types of parking infringement, although at present in Great Britain most carry the same penalty. For most offenses, traffic wardens have three options: a parking ticket (£12), wheel clamping the vehicle (central London only), or towing the vehicle. Table 3 summarizes responses to a question on the appropriate action involving an illegally parked car in seven different situations.

Parking illegally in a bus lane or on a white zigzag line were felt to deserve strong penalties. Conversely, 20 to 25 percent said that nothing should be done about cars parked illegally on a single yellow line (which bans parking but allows loading during the working day), or in a residents' parking space. People tended to regard parking on a double yellow line as much more serious than parking on a single yellow line, although they both carry the same penalty (the difference is in the period of time over which parking is banned).

Although the issue of a parking ticket was the most frequently recommended action, in cases of infringements that were perceived to be very serious, a sizable proportion of respondents favored the use of wheel clamps or towing the vehicle away, with a general preference for the latter. The argument used was that such strong measures are only justified where the parking infringement was a safety hazard (white zigzag line), or caused congestion (bus lane or double yellow line), or was antisocial (parking in a handicapped space). Wheel clamping tended to exacerbate the problem in the public mind by keeping the offending vehicle there longer and so was felt to be the worst action from a traffic point of view. The cost effectiveness and deterrent value of wheel clamping were not fully appreciated by the public, although this procedure is strongly supported by professionals. A policy of concentrating vehicle removals on offenses perceived to be a safety hazard and a cause of congestion would receive strong public support.

The following differences in attitude were observed:

- Respondents who drove for a living and those in households with a car available were more likely to support towing when the offense was a safety hazard (white zigzag line) or caused congestion (double yellow line or car parked in bus lane).
- Respondents from households with a car were slightly more tolerant of people parking on single yellow lines (22 percent said do nothing, compared with 15 percent from households without a car). When the offense concerned who parks in a space, differences were negligible.
- In most cases, a strong relationship existed between reported noncompliance or perceived seriousness and the type of parking penalty recommended. For example, 52 percent of the people who often parked on single yellow lines said do nothing, compared with 14 percent of those who never break the regulation.

CONCLUSIONS

A number of insights into public attitudes toward traffic regulation and enforcement in Great Britain were gained, and

TABLE 3 RECOMMENDED ACTION AGAINST ILLEGAL PARKING

SITUATION	ACTION SUPPORTED: Tow Away	Wheel Clamp	Issue Ticket	Do Nothing
Car parked in bus lane in rush hour	60%*	4%	27%	3%
Car parked on white zig zag	40%	8%	42%	5%
Car left in disabled space	28%	10%	49%	7%
Car parked on double yellow	19%*	15%	59%	3%
Car left in residents' space	13%	7%	46%	26%
Car parked on single yellow	6%	5%	61%	20%
Overstaying permitted time	6%	7%	70%	12%

* Stronger support for tow away among those who drive as part of their job.

General public reaction: *"Towing away for the more serious offence and tickets for the less serious offence."*

12 factors that influence compliance were identified. Simple, clearly signed regulations that are obviously needed and have few exemptions are likely to be best observed. Although most drivers break regulations, at least occasionally, better enforcement of certain types of offenses is strongly supported, especially where the objective of the regulation is seen to be road safety or congestion relief.

The purpose of the research was to obtain a consumer view on traffic regulation issues, and these findings need to be balanced against the concerns and judgments of the professionals involved in urban traffic regulation. Nevertheless, the views expressed by the public are clearly of wide-ranging significance and relevance to all those involved in the resolution of traffic problems in urban areas.

(A leaflet summarizing the key findings of the whole study has been produced by the Department of Transport's Traffic Advisory Unit as *Traffic Topics 1*, and is available free of charge from Traffic Policy Division, Room C10/12, Department of Transport, 2 Marsham Street, London, SW1P 3EB, England.)

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The views expressed are those of the author and do not necessarily represent those of the Department of Transport.

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Building an Accident Report Data Base for Local Agencies

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A microcomputer accident report input and analysis system was adapted for the use of local police and engineering agencies. The Accident Report Entry System (ARES) conforms to current state rules for coding, internal consistency, and edit checks. As adapted, it permits agencies to enter their own traffic accident data from Michigan's standard accident report form, the UD–10. For the local jurisdiction, the ARES software also locates the accident on the Michigan public roadway system and determines a road number and milepoint. This task was previously done only on the Michigan State Police (MSP) mainframe computer. Historically, local agencies have had limited access to state-entered accident information. Using ARES, they can now enter their own UD–10 data to the same standards as those of the MSP. The information is available for study immediately, whereas mainframe data have recently been delayed for long periods and are not always in a form convenient for local users. Output reports equivalent to MSP standard analytical reports are already available locally. More advanced reporting capabilities similar to the sophisticated methods now in use at the Illinois Department of Transportation are being developed.

Michigan has long had a mainframe-based system for recording traffic crash data (*1*). This system is able to locate properly described accidents on all of its approximately 115,000 mi of public roads. The roadway data base is called the Michigan Accident Location Index (MALI) and is maintained on a Michigan State Police (MSP) mainframe computer. The index has a unique number for every road segment, as well as a milepoint for every intersection. The Michigan Office of Highway Safety Planning (OHSP) has supported the creation of microcomputer software to deal with several aspects of accident records. One group of programs permits the extraction of the subset for a county or city road system from the mainframe's statewide road index. This subset is almost always small enough to be manipulated effectively on a microcomputer.

A second series of programs for the Accident Report Entry System (ARES) allows a local police or engineering agency to create a local data base of traffic crash records for their own jurisdiction. These programs have been described elsewhere (*2,3*). Extensive details of the software appear in two manuals (*4,5*), one for the operator and another for the programmer. The operator sits at a personal computer (PC) and enters data from the UD–10 report, using screen forms similar to those used by the MSP. Some of the data are taken directly from the UD–10, and other information is heavily encoded into a compact format. Encoding was needed formerly to save mainframe memory and disk storage, but it is hardly necessary today, even on small machines. Encoding has been retained primarily to conform to state procedures. In the future, the state might benefit from paying local agencies for each accident report entered according to proper standards; local police and agencies, of course, benefit from the immediacy of the data. The disadvantages are that operators need training in coding and have to enter data that have little value for local agencies, but they could be offset by state payments.

ARES abides by MSP rules and could replace the existing system if this were desired. The replacement would probably be best implemented as a local-area PC network, usually more economical today than a minicomputer. A study of the present system indicates that a considerable amount of paper handling could be avoided if ARES became a state system. However, all state institutions have adjusted to the present system, and much dislocation would result. From the viewpoint of standardization, quality, and training, having both the central data entry system and a local agency work with exactly the same software would be desirable. But combining the software may place an extra burden on local agencies that want to use ARES and may not need all of the data and cross-checks now incorporated for state purposes. The situation will probably become clearer after further experience.

One advantage of ARES is that the mainframe no longer has to be used at all. ARES makes location determinations right on the microcomputer. Accident reports are very clean before they are added to the local data base, because ARES furnishes on-line diagnostics and many checks before it accepts a record. Before the creation of ARES, the inflexibility of the prevailing system limited timely and convenient access by local agencies to their own accident data, and inhibited systematic analysis by these agencies. A plan for modifying the state system is being studied, in response to questions raised at Michigan's 1987 Governor's Conference on Highway Safety.

Local users must have a good reason to create their own data base, or the effort is not worthwhile. In addition to improving public safety, good data analysis can facilitate effective engineering and law enforcement countermeasures, and thus is a prime defense against tort liability. Local groups must learn how to use the information buried in accident data. Until now, the available accident data often arrived too late to be of much value in law enforcement or roadway improvement. The current pressure of tort liability judgments has become a powerful inducement for local agencies to learn how to use accident analysis in self-defense, and interest in

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doing so is growing. Accordingly, a training program in accident data analysis is considered to be a vital follow-up to current project developments.

PROJECT OBJECTIVES

The original project was altered after a reorganization of the MSP data processing unit and was refocused toward the needs of local users. Originally, the ARES system was intended to replace the central data entry procedures of MSP, and that objective can still be seen in the details following. At this time, many but not all of the following objectives have been achieved:

- Create a data input system for a local agency that conforms to the current state format, with all existing cross-checks and consistency checks. Create software that is as independent as possible of the particular microcomputer hardware used. Try to use the inexpensive equipment that is often all that local agencies can afford.
- Use commercially available data base management software, because it is relatively easy to use and good programmers are normally available for such packages. Furnish online operator assistance. Nonprogrammers and relatively inexperienced computer users should be able to learn the system quickly.
- Furnish analysis software so that timely action can be taken by local engineering and police personnel to make optimum use of their limited resources. Create a report system guided by the practices of major state agencies and other large users, but one that is adapted to the needs of local agencies.
- Explore graphical representations of accident data, such as collision diagrams, which make it easier for unsophisticated users to comprehend the significance of the data. Extend the system to integrate related functions, such as citations and court actions.
- Search out and use related projects in other states and incorporate their ideas where practical.
- Encourage the creation of training programs in the use of data entry and data analysis software.

EARLY RESULTS

Tests of several objectives were carried out at the MSP central data entry location, at a time when a microcomputer network was being given feasibility tests as a replacement for the existing minicomputer system. At present, an assembly line of personnel go through processes called locating, coding, and data entry, accompanied by much paper handling. Only the data entry clerk actually sits at a computer terminal. The ARES system was designed to have all these functions performed by a single person at a single machine, entering data for a single county or city. Location was designed to take place on the microcomputer, to avoid the 20 to 25 percent report rejection rate on the mainframe, caused almost entirely by location difficulties. The early prototype software worked on the MS-DOS operating system using a version of the R:BASE commercial data base package. The microcomputers were IBM PC ATs or compatibles.

Roadway data bases are normally too large to fit into the 640 kilobytes of MS-DOS memory, and searching for a road in a data base on a hard disk takes too much time for a production environment. The practical solution is to add large amounts of memory and place the entire data base in a virtual or random access memory (RAM) disk. Typically, 5 to 7 megabytes of RAM disk is needed for all but the largest counties or cities, to have room for both a roadway description network and a reasonable amount of accident data. The data base program itself sits in normal DOS memory as usual. The data base must be saved frequently on the hard disk (which is just a menu selection for the operator). As a conservative practice, the hard disk actually contains the current date's data base, another that is 1 production day old, and a third that is 2 production days old. In addition, each successfully added record is written out as pure for the American National Standard Code for Information Interchange (ASCII) data in another region of the hard disk.

In the prototype feasibility test, six operators were selected by the MSP supervisor from the existing MSP data entry staff. The operators had a range of experience with the present state system and were carefully selected to avoid using unusually poor or good performers. Over 1,000 accident reports were processed on the experimental system during a period of about a month, with the system being debugged as necessary. The average entry time for all operators over all reports was about 20 percent shorter on the prototype than on the existing system. Not much time was expected to be saved, because the same amount of diagnosis is needed for the existing and the experimental systems, and the same average number of keystrokes is needed for both. On the basis of the results, it was estimated that an experienced, fulltime operator could enter 18,000 to 20,000 Michigan-style reports per year, even with the early, slow, bug-infested software. Operator response was positive.

These results established the feasibility of carrying out the location process on a single PC (rather than exclusively on a mainframe), and of using a single person at a single machine to perform the necessary work. Current, bug-free versions of the software for data input are faster, more reliable, and kinder to the operator.

Part of the project was to test the software at a cooperating locality. The police and traffic engineering groups of the city of Battle Creek agreed to examine the value of entering and analyzing their own data. Battle Creek personnel were trained by the MSP in state data entry methods. A staff member of traffic engineering then entered about 1,000 accident reports over a period of several months. The software was continually updated in response to operator experience. Locating the accidents on a microcomputer produced the same results as on the mainframe, when the same input data were entered and the same roadway description network was used. Every discrepancy in location between the MSP mainframe and the Battle Creek microcomputer was accounted for. The software has now been adjusted to reduce those discrepancies, which can be attributed to operator choices. Further checking is in progress, but the project proceeds with confidence.

Practical application of ARES outside Michigan may be possible, depending upon how other locating systems for accidents (if any) function. ARES can be adapted to a variety of locating schemes. The real question is: "What data should be

```
Michigan State University
Department of Civil and Environmental Engineering

Accident Report Entry System (ARES Version 1.0) 26 April 1989

Please enter your name, or RETURN to quit:  David
```

```
Main Menu
(1) Enter a new record
(2) Resume editing an incomplete record
(3) Correct an existing complete record
(4) List unlocated reports   [Followup on operator override]
(5) Change operator name [Machine left on between operators]
(5) Save database (coffee break time)
(6) Quit production for the day (save database, exit to DOS)
```

FIGURE 1 R:BASE startup screen (*top*) and main menu (*bottom*).

```
Accident Location Information                  [Screen 1]

Reel 93       Frame 3112      Lein 11      Compl 11-3692-87

Accident Number 333333    Date 12/04/87     Time 3   pm

County 33              Township 9

Primary Road E I96

Distance 0.2         Units (mi/ft) mi      Direction E

Intersecting Okemos
```

REEL and FRAME refer to microfilm storage; COMPLaint is the local police report No.; ACCIDENT NUMBER is a State Police No.; the accident occurred on Eastbound I96, 0.2 miles EAST of the intersection with Okemos (Road) in Ingham County (33) Township No. 9.

```
Accident Conditions       333333 [Rept. No.]        [Screen 2]

Area 999    Pseudo      Rd Align 6  Traffic 0    Road Loc 3

Acc.Type 3 Where 4      How 0       Tags 9       Road Defect 0

#Units 2    #Parked 0  #Drivers 2  #Injuries 1  #Killed 0

Weather 3   Light 1     Surface 2   Const.Zone N  At Scene Y
```

AREA is "highway area type"; PSEUDO is used for failure to locate in the stated district; RD ALIGNment is "curved" vs. "straight" etc; TRAFFIC is for type of traffic control device or person; ROAD LOC is the road location code; ACC.TYPE WHERE HOW is a complex of codes describing and classifying the accident; TAGS is a special State Police accident designation; #UNITS means No. of vehicles or cyclists or pedestrians; SURFACE refers to "wet" or "dry" etc.; AT SCENE means "investigated at accident scene".

FIGURE 2 Screens showing accident location information and conditions from Michigan accident form UD-10.

```
Vehicle/Driver Information        333333        [Screen 3]

Unit # 1      [Auto #1 in accident, first of 2 screens]

Residence 5       Intent 01         Direction E

Obj. Hit  0       Situation 9       Contr. Circ. 9

Veh. Defect 8     Visual Obstruct 0      SOS 0

State MI        Lic c325-429-723-045     DOB 1/16/47

First name  JOHN     Middle  QUINCY     Last  CITIZEN
```

RESIDENCE (of driver); driver INTENT and OBJect HIT; SITUATION and CONTRibuting CIRCumstances; SOS item is for Secretary of State; and the LICense has been SOUNDEX-encoded from the driver name and DOB = date of birth.

```
Vehicle/Driver Information (cont'd)    [Screen 4]

Unit # 1          [2nd of two screens for first driver]

Haz Act 8     SOS Haz Act 8

HBD Y      Test .02    Helmet N   Age 40       Sex M      Inj O

Year 85    Make 02     Type 1     Trailer 0    VIN 6G367E55638

Haz Cite Y   Other Cite N    Driveable N   Leakage N  Fire N

Impact 1     Severity 2      Spillage N    Class 9

Total Occupants 2      Restraints B1-  -  -  -  -
```

HAZardous ACTion is first classified by a police officer and perhaps differently by a coder (as SOS HAZ ACT); HBD=had been drinking; TEST gives alcohol test data; INJ O is "uninjured"; MAKE/TYPE/TRAILER classifies the vehicle; HAZ CITE = citation by officer; DRIVEABLE refers to the vehicle; IMPACT locates the point; SEVERITY classifies the accident; and RESTRAINTS encodes belt usage at up to 6 positions.

FIGURE 3 Vehicle and driver information screens.

entered?" The answer is probably different for different localities, and it is here that major departures from state and national schemes may be advisable. If no appropriate scheme exists already, it would be helpful if NHTSA could develop a suggested scheme for nationwide data collection at the local level, focusing the ideas in the original Highway Safety Improvement Program (HSIP) of 1981 (*6*) on local needs.

DETAILS OF ARES FOR INPUT

The ARES system uses the data base program called R:BASE for DOS on fast microcomputers based on the Intel 80286 CPU. This program is easily adapted to most local jurisdictions in Michigan, but an 80386 machine may be needed for the largest regions. Some operator training will always be necessary if data entry is to conform to state rules and standards. Local units of government may or may not actually need to enter precisely the same data that the state as a whole may wish to collect.

Figures 1 through 12 show a subset of the screens and menus that the operator sees, just to give the flavor of the system. Many have been omitted to save space. The displays normally fill the video screen, but they have been reduced in size. Any items in square brackets are for clarifying comments. Figure 1 shows the first screen seen by the operator after R:BASE starts and the main menu screen.

Selecting Item 1 from this menu results in a series of screens. Screens 1 and 2 appear once per accident report form (see Figure 2). All items come directly from Michigan accident form UD-10. Most of the top half of Screen 2 contains heavily encoded information for the Michigan Department of Transportation (MDOT) and the MSP, requiring operator training and judgment to enter it.

Screens 3 and 4 in Figure 3 are for vehicle and driver information, and Screen 5 in Figure 4 is for details of nondriver

```
                    Injury Data      333333            [Screen 5]

                    Unit      Pos     Age   Sex   Inj   Helmet
    Injury 1         1         3       21    F     A      N
    Injury 2         0         0       0
    Injury 3         0         0       0
    Injury 4         0         0       0
    Injury 5         0         0       0
    Injury 6         0         0       0
    Injury 7         0         0       0
    Injury 8         0         0       0
```

The injured person is in POSition 3, with disabling INJury, type "A".

```
Choose report to RESUME, or press ESC for the main menu.

         3688  Unable to locate
        27564  UD-10 sent back for correction
```

User moves cursor keys and presses Return/Enter to select a highlighted report (cannot be simulated here) for RESUMEd editing.

```
                        Select an option
     (1)  Edit Location data              [returns to 1st screen]
     (2)      Accident Conditions         [returns to 2nd screen]
     (3)      Vehicle/Driver Information      [3rd & 4th screens]
     (4)      Injury Data (passengers 1-8)          [to Screen 5]
     (5)      Injury Data (passengers 9-16)         [to Screen 5]
     (6)      Injury Data (passengers 17-24)        [to Screen 5]
     (7)      Supplementary SOS Information           [not shown]
     (8)  SAVE AND CONTINUE                        [to MAIN MENU]
```

FIGURE 4 Nondriver injury data (*top*) and resume editing (*bottom*) screens.

```
LOCATE Version 2.0 of 30 January 1990
--------------------------------------
Locating WASHINGTON intersecting with MAIN
Searching for primary road:  Found
                 crossroad:  Found

 Mile-     Primary Road                       Crossroad
 point     PRN        Name                    PRN          Name

  3.21     1234567    WASHINGTON DR           4444444      MAIN AVE
  0.17     7654321    WASHINGTON ROAD         4444444      MAIN AVE
```

Cursor highlights a row in the menu above (not visible in this simulation). Operator moves highlighted row with cursor keys and selects with Return/Enter key: resolves roadway name ambiguity.

```
SOUNDEX            Entered                    Computed
-------            ------------------         ----------
First Letter       B                          B       OK
Last Name          BLOW                 350   350     OK
First Name         JOE                  450   450     OK
Middle Name        QUINCY               546   548     BAD
Birth Date         05/10/66             357   357     OK
```

FIGURE 5 Example of a correctable Soundex check that did not work the first time.

```
[ ARES Analysis Version 1.0 5/15/89 -- Main Menu ]
        (1)  Michigan State Police Standard Reports
        (2)  Other Standard Reports
        (3)  Custom Reports
        (4)  Examine Road Network
        (5)  Exit to R:BASE
        (6)  Exit to DOS
```

```
[ ARES Analysis 1.0 -- MSP Standard Reports ]
        (1)  Intersection Search
        (2)  Segment Search
        (3)  Intersection High Rank
        (4)  Return to the Main Menu
```

[Abbreviation PRN below is for the official MALI road number.]

```
Michigan State Police Standard Report
Intersection Search

SELECTING ROADS BY NAME OR PRN

When selecting a road, you may either enter the road name,
or the PRN preceded by '#'.  For example, if you wish to
select by the name, at the prompt you would enter:

              COLUMBIA

To select by PRN, at the prompt you would enter:

              #1297108

For Absolute Township, use 1000 * (county no.) + (twp no.)

Enter Absolute Township (RETURN to include all townships): 13080
Enter Main Road: #1298109
Enter Crossroad (or RETURN for menu): DICKMAN
Enter Intersection Search Radius (RETURN for none): 125
```

FIGURE 6 ARES startup (*top*), MSP standard reports (*middle*), and intersection search (*bottom*) menus.

injuries. In Screens 3 and 4, the data entry operator must again encode many items. Here Screen 5 is for an injury in Unit 1.

Selecting Item 2 in the main menu of Figure 1 results in the resume screen of Figure 4. If main menu Item 3 is selected (see Figures 1 and 4), the "Select an option" menu displayed there appears.

Figure 5 shows the screen seen during the ordinary processes of location, after Screen 1. This form of display helps resolve roadway name ambiguity.

Soundex checking (Figure 5), which is part of the ARES system, strictly for the U.S. Department of State, verifies whether the driver license numbers agree with the date of birth and driver name. While the Soundex routine is calculating what the numbers should be from the name and birthdate, these numbers and the original entries appear on the screen. If no problem is discovered and all items are the same, the screen clears and the program continues. If a problem occurs and one or more of the numbers do not match, the numbers stay on the screen until the operator presses a key. Thus, the numbers can be examined and the difficulty can be corrected. Figure 5 shows an example of a (correctable) Soundex check that did not work the first time.

The many other screens and error messages must be omitted here. Operators and users have a reference and training manual (*4*), which has more than 220 pages and includes most of the instructions for MSP coders. The *Programmers Manual* (*5*) is of comparable size.

FEATURES OF ARES FOR OUTPUT

At present, MSP and MDOT furnish various standard reports to interested users, based on data in MSP's master accident

```
Michigan State Police Standard Report
Intersection Search
   Select road for DICKMAN

S  13080 1296303   DICKMAN ROAD
   13080 1297110   DICKMAN ROAD
W  13080 1300503   DICKMAN ROAD  either enter the road name,
o  13080 1300702   DICKMAN ROAD  r example, if you wish to
s  13080 1298108   DICKMAN ROAD  pt you would enter:
   13080 1296303   DICKMAN ST

T                                 you would enter:

F                                 * (county no.) + (twp no.)

Ent                              o include all townships): 13080
Enter Main Road: #1298109
Enter Crossroad (or RETURN for menu): DICKMAN
```

```
              R E P O R T   P A R A M E T E R S
              ARES Analysis Version 1.0  15 May 1989

     ABTWP: 13080                    Report Type: Segment Search

   Main Road: 1297108    COLUMBIA AVE
   Crossroad: not selected

   Intersection Search Radius (feet):  not using search radius

            Period: from 01/01/88 to 04/01/88

   Segment (miles): from 0. to 2.525  (31ST STREET)

        [ Select Option (ESC to QUIT, F10 for help) ]
   Edit   Clear  Print  Quit
```

FIGURE 7 Intersection search pop-up menu (*top*) and report parameters (*bottom*).

tapes. These tapes mainly contain the data entered by the central-site operators, but they also include the location data created by the MSP mainframe. A few other calculations are performed, but the output is almost the same as the input. User groups who have examined the matter believe that only input data (plus computed location) should be stored. Only then can users know the precise meaning to ascribe to every data field. The philosophy of ARES output follows this idea of storing and analyzing raw input data alone.

ARES input is first converted to ARES output by a program devised for that purpose. It changes many numerical codes, such as 2 or 14, into intelligible items like Rain or Snow, or into abbreviations like FaiYi, for Failure to Yield. The output data base omits the tables that are needed for input but have no purpose during output.

The user who starts ARES output sees a startup menu (Figure 6). Here, Option 1 delivers reports adapted from those now provided by MSP or MDOT. These reports are being used at the cooperating agencies in Battle Creek. They consist of regular R:BASE reports, speeded up by interfacing R:BASE with C-language utilities for which R:BASE cannot do what is necessary quickly enough. Option 2, still undergoing development, is much more advanced. These reports incorporate some of the ideas used by the Illinois Department of Transportation (DOT) but require additional tables of data, which have only just been obtained. These extra data consist of traffic volumes and elements of roadway geometry. Custom reports, Option 3, must be crafted by those who know the R:BASE system well and can create ad hoc reports for themselves. After choosing Option 1 of Figure 6, the user receives the second menu shown.

If the user selects the intersection or segment searches from this menu, the last screen of Figure 6 appears and the user is prompted for data. When entering a road name, such as Dick-

INTSRCH

L O G O F A C C I D E N T S

Period: YTD 88

Location: CAPITAL and COLUMBIA AVE

Accidents within 125 feet of the intersection.

Page 1

07/21/89 14:39:44

*** Accident happened on 1297309--CAPITAL (DR above = Direction)

Accid. Rept.	Mile Point	Dist.	Dir	Intersecting Street	Accident Type	Sev	Date	Time & Day		Wthr	Surf	Lght	Vehicle #1 DR	Vehicle #1 Hazact	Vehicle #1 HBD	Vehicle #2 DR	Vehicle #2 Hazact	Vehicle #2 HBD
3717	5.526	0.019	s	1297108--COLUMBIA AVE	cMVh	pd	01/30/88	10	Sat	Clr	Wet	Day	s	ImpBk	n	n	NoVio	n
6853	5.526	0.019	s	1297108--COLUMBIA AVE	cMVh	pd	02/24/88	7	Wed	Clr	Icy	Day	n	NoVio	n	n	NoVio	n
19781	5.526	0.019	S	1297108--COLUMBIA AVE	cMVh	pd	05/24/88	16	Tue	Clr	Dry	Day	E	FaiYi	N	N	NoVio	N
19759	5.526	0.019	se	1297108--COLUMBIA AVE	cMVh	inj	05/23/88	9	Mon	Clr	Dry	Day	n	TooCl	n	n	NoVio	n
34804	5.526	0.019	S	1297108--COLUMBIA AVE	cMVh	pd	08/25/88	15	Thu	Clr	Dry	Day	S	WrgTr	N	N	NoVio	N
25975	5.536	0.009	s	1297108--COLUMBIA AVE	cMVh	pd	07/01/88	13	Fri	Clr	Dry	Day	n	TooCl	n	n	NoVio	n
9192	5.539	0.006	s	1297108--COLUMBIA AVE	cMVh	pd	03/13/88	21	Sun	Snow	Icy	StLi	e	TooFa	n	n	NoVio	n
36091	5.553	0.008	N	1297108--COLUMBIA AVE	Othr	pd	09/03/88	1	Sat	Rain	Wet	StLi	S	TooCl	Y			
16600	5.556	0.011	n	1297108--COLUMBIA AVE	cMVh	pd	05/05/88	17	Thu	Clr	Dry	Day	s	OthUk	n	s	NoVio	n

*** Accident happened on 1297108--COLUMBIA AVE [This list edited out to save space on page but SUMMARY in next Figure contains removed data, which is for part of 1988 only.]

cMVh = collision with moving vehicle; pd = property damage; inj = injury accident; StLi = dark, street lights
Day = daylight; NoVio = no violation; WrgTr = improper turn; TooFa = too fast; TooCl = following too closely

(Continued in Fig. 9)

FIGURE 8 Page one of actual intersection search and summary from partial-year Battle Creek data.

INTSRCH
SUMMARY

LOG OF ACCIDENTS
Period: YTD 88
Location: CAPITAL and COLUMBIA AVE
Accidents within 125 feet of the intersection.

Page 2
07/21/89 14:39:51

Single Vehicle Overturned	0
Single Vehicle in Collision with:	
Railroad-Train	0
Parked Vehicle	0
Pedestrian	0
Fixed Object	0
Other Object	0
Animal	0
Pedalcycle	0
Other or not known	1
Collision with Moving Vehicle (total)	(8)
Both Going Straight	0
Sideswipe	0
Left Turn Involvement	0
Right Turn Involvement	1
Stopped or Disabled	4
Backing Into	1
Entering Parking or Driveway	1
Leaving Parking or Driveway	1
Starting or Stopping	0
All Others	0

VEHICLE TYPE	
Passenger Car	16
Truck	1
Motorcycle	0
School Bus	0
Commercial Bus	0
Farm Equipment	0
Construction Equip	0
Emergency	0
Snowmobile, Dune buggy, other offroad	0
Pedestrian	0
Bicycle	0
Other Road Vehicle Except Pedalcycle	0

DRINKING / DRUGS	
Had Been	1
Had Not Been	16
Not Known	0
Total	17

HAZARDOUS ACTION	
No Violation	9
Too Fast	1
Too Slow	0
Failure to Yield	1
Wrong Way	0
Wrong Side	0
Improper Turn	1
Improper Backing Up	1
Too Close	3
Other/Unknown	1
TOTAL CITATIONS	8

ACCIDENTS		PERSONS	
Fatal	0	Killed	0
Injury	1	Injured	1
Property	8	TOTAL	1
TOTAL	9		

WEATHER CONDITIONS	
Clear/Cloudy	7
Fog	0
Raining	1
Snowing	1
Other/Unknown	0
Total	9

SURFACE CONDITIONS	
Dry	5
Wet	2
Snowy or Icy	2
Other/Unknown	0
Total	9

FIGURE 9 Page two of actual intersection search and summary from partial-year Battle Creek data.

DRIVER PROFILE

Age Group	Drinking or Drugs No	Drinking or Drugs Yes	RESIDENCE County	In-State	Out of State	Driverless	Other	TOTAL
16-25	5	0	4	1	0	0	0	5
26-55	9	1	8	0	0	0	0	10
56-98	1	0	1	0	0	0	0	1
99	1	0	0	0	0	0	0	1
TOTAL	16	1	13	1	0	0	0	0

FIGURE 10 Driver profile of actual intersection search and summary.

man in the sample screen, a pop-up menu displays all the Dickmans in the data base of the townships specified, for the user to select. This list is shown in Figure 7. The user can now edit report parameters, as in the segment search in the lower part of Figure 7. A highlighted cursor (not visible here) permits selection among the choices. EDIT allows changes in the data, CLEAR removes all entries, QUIT or ESC quits, and PRINT pops up the printer control menu (not reproduced here). An actual intersection search and summary using partial-year Battle Creek data is shown in Figures 8–10.

A sample segment search is shown in Figure 11, with the summary portions shown in Figures 8–10 omitted. Figure 12 shows the leading portion of the intersection high rank report, which does not change often or need to be run frequently. This last standard report does not allow for traffic volumes and other factors. Unfortunately, this version of ranking is quite common and is often all that is available; it will be improved as soon as the Illinois DOT software can be introduced.

Option 4 of the main menu (examine road network, Figure 6) makes use of the local roadway network, which is already in the data bases for both input and output. Using this branch, all road names corresponding to a given road number, such as 1297108, or all road numbers that go with a given name (like Main St) can be retrieved. For every road number, the milepoint, road name, and road number corresponding to every intersection on that road can be inspected. The other main menu options are self-explanatory.

FUTURE PLANS

The City of Battle Creek continues detailed testing of input and output software. The sophisticated analysis scheme used by the Illinois DOT for its trunklines is being incorporated into the Battle Creek project. This incorporation requires traffic volume and geometry data, only recently obtained. As soon as good software has been thoroughly tested, other local agencies in Michigan will be able to use the entire ARES system. A significant number of agencies are known to be interested. Considerable thought will be given to reducing the data entered to that really needed by local agencies. This reduction may offer savings of entry time and operator training and should be explored if it does not impinge on data quality and adequacy.

Other aspects of a complete Highway Safety Improvement Program will be integrated gradually into the ARES system. Police citations, court records, and other factors that affect traffic safety probably have a place in the overall picture. If the project proves to be successful, short courses and training will also need to be devised as a follow-up.

CONCLUSION

An accident data system like that now used by the MSP can be implemented on a microcomputer, for a jurisdiction as large as an above-average county in the state, or a city of comparable size. The ARES software is able to extract an appropriate subset of the statewide road network (MALI Index). This permits ARES to locate accidents on public roads without requiring a mainframe or even a minicomputer. Thus, local engineering or police agencies can use an inexpensive machine to enter their own accident data and to analyze it immediately with the software now being refined. In turn, this should help to improve both public safety and the tort liability problems of many local jurisdictions.

ACKNOWLEDGMENTS

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SEGSRCH

LOG OF ACCIDENTS
Period: YTD 88
Location: COLUMBIA AVE from 3.2 to 3.70

Page 1
07/28/89 15:25:35

*** Accident happened on 1297108--COLUMBIA AVE (DR above = Direction)

Acc. Rept.	Mile Point	Dist	Dir	Intersecting Street	Accident Type	Sev	Date	Time & Day	Wthr	Surf	Lght	Vehicle #1 DR	Vehicle #1 Hazact	Vehicle #1 HBD	Vehicle #2 DR	Vehicle #2 Hazact	Vehicle #2 HBD
4132	3.201	0.000	X	1309610--20TH ST	cMVh	inj	02/02/88	11 Tue	Clr	Wet	Day	w	FaiYi	n	s	NoVio	n
35014	3.206	0.005	e	1309610--20TH ST	cObj	pd	08/26/88	20 Fri	Clr	Dry	Dusk	w	NoVio	n			
19666	3.215	0.014	e	1309610--20TH ST	cMVh	inj	05/23/88	20 Mon	Clr	Dry	Day	w	TooCl	n	w	NoVio	n
11114	3.220	0.019	e	1309610--20TH ST	cMVh	pd	03/28/88	13 Mon	Rain	Wet	Day	w	FaiYi	n	e	NoVio	n
31728	3.239	0.038	E	1309610--20TH ST	cMVh	inj	08/05/88	18 Fri	Clr	Wet	Day	W	TooCl	N	W	NoVio	N
2576	3.288	0.028	w	1309403--WOODROW ROAD	cMVh	pd	01/21/88	7 Thu	Clr	Dry	Dusk	w	TooCl	n	s	NoVio	n
29001	3.297	0.019	w	1309403--WOODROW ROAD	cMVh	pd	07/20/88	0 Wed	Rain	Wet	Day	e	TooFa	n	w	NoVio	n
38464	3.301	0.100	e	1309610--20TH ST	cMVh	pd	09/18/88	16 Sun	Rain	Wet	Day	w	TooCl	n	w	NoVio	n
405	3.312	0.004	W	1309403--WOODROW ROAD	cMVh	inj	01/04/88	15 Mon	Snow	Icy	Day	W	FaiYi	N	E	NoVio	N
10262	3.316	0.000	X	1309403--WOODROW ROAD	cMVh	pd	03/22/88	8 Tue	Clr	Dry	Day	n	FaiYi	n	e	NoVio	n
105	3.321	0.005	ne	1309403--WOODROW ROAD	cMVh	pd	01/01/88	21 Fri	Clr	Dry	StLi	w	TooFa	n	w	NoVio	n
17447	3.322	0.006	e	1309403--WOODROW ROAD	Othr	inj	05/10/88	16 Tue	Clr	Dry	Day	w	NoVio	n			
11135	3.335	0.019	e	1309403--WOODROW ROAD	cMVh	pd	03/28/88	16 Mon	Rain	Wet	Day	e	TooCl	n	e	NoVio	n
17723	3.373	0.057	w	1309604--ARBOR	cMVh	pd	05/12/88	13 Thu	Clr	Dry	Day	s	FaiYi	n	w	NoVio	n
37080	3.383	0.047	W	1309604--ARBOR	cMVh	pd	09/09/88	23 Fri	Clr	Dry	StLi	N	NoVio	N	E	NoVio	n
6320	3.411	0.019	w	1309604--ARBOR	cMVh	pd	02/19/88	16 Fri	Snow	Wet	Day	e	TooCl	n	e	NoVio	n
34003	3.411	0.019	W	1309604--ARBOR	cMVh	inj	08/19/88	23 Fri	Clr	Dry	StLi	W	TooCl	N	W	NoVio	N
34114	3.417	0.013	W	1309604--ARBOR	cMVh	pd	08/20/88	18 Sat	Clr	Dry	Day	E	WrgSi	N	E	NoVio	N
9026	3.428	0.002	w	1309604--ARBOR	cMVh	inj	03/12/88	11 Sat	Clr	Wet	Day	e	TooCl	n	e	NoVio	n
13311	3.431	0.001	ne	1309604--ARBOR	cMVh	inj	04/12/88	14 Tue	Clr	Dry	Day	e	WrgTr	n	w	NoVio	n
8545	3.432	0.002	ne	1309604--ARBOR	cMVh	pd	03/08/88	18 Tue	Clr	Wet	StLi	w	NoVio	n	n	FaiYi	n
38628	3.435	0.005	se	1309604--ARBOR	cFix	pd	09/19/88	17 Mon	Rain	Wet	Day	e	NoVio	n			
17275	3.449	0.019	e	1309604--ARBOR	cMVh	inj	05/09/88	13 Mon	Clr	Dry	Day	w	TooCl	n	w	NoVio	n
1985	3.573	0.001	e	1309609--LA VISTA BLVD	cMVh	inj	01/16/88	18 Sat	Clr	Wet	StLi	e	TooFa	n	w	NoVio	n
23497	3.578	0.006	e	1309609--LA VISTA BLVD	cMVh	pd	06/16/88	13 Thu	Clr	Dry	Day	w	TooCl	n	w	NoVio	n
31309	3.646	0.019	NW	1314501--LINDALE CT	cMVh	pd	08/03/88	0 Wed	Clr	Dry	Day	E	TooCl	N	E	NoVio	N
15326	3.669	0.004	e	1314501--LINDALE CT	cMVh	pd	04/27/88	0 Wed	Clr	Wet	Day	e	TooFa	n	e	NoVio	n
24393	3.671	0.006	e	1314501--LINDALE CT	cMVh	pd	06/21/88	22 Tue	Clr	Dry	StLi	e	FaiYi	n	w	NoVio	n
38174	3.699	0.009	w	1314801--SYLVAN ST	cMVh	inj	09/16/88	21 Fri	Clr	Dry	StLi	e	TooCl	n	e	NoVio	n

FIGURE 11 Sample segment search.

```
INTERSECTION          I N T E R S E C T I O N   L O G        Page  1
ABS HIGH RANK                                          7/28/89 15:17:29
          All accidents within 150 feet of the intersections
                                                                    No.
Main Road                Crossroad                Milepoint     Accid
---------------------------------------------------------------------
1297309 CAPITAL          1297108 COLUMBIA AVE      5.54500         29
1297204 N B DR           1297309 CAPITAL           3.31700         19
1298703 BEDFORD ROAD     1298109 M 37              0.00000         18
1297108 COLUMBIA AVE     1296608 RIVERSIDE DR      4.68000         17
1298109 M 37             1298906 WASHINGTON AVE    6.40500         16
1300106 EMMET            1299810 NORTH AVE         0.50200         15
1297108 COLUMBIA AVE     1314801 SYLVAN ST         3.70800         15
1296304 GROVE ST         1310307 HAMBLIN AVE       0.89600         15
1297108 COLUMBIA AVE     1309203 24                2.96200         14
1299810 NORTH AVE        1303602 ROOSEVELT AVE     1.28000         14
1303401 CALHOUN ST       1298906 WASHINGTON AVE    0.44100         14
1297309 CAPITAL          1298804 W M37             7.58500         13
1309601 TERRITORIAL RD   1309610 20TH ST           1.59700         13
1297309 CAPITAL          1300106 EMMET             9.09500         13
1297309 CAPITAL          1299907 FREEMONT          7.83600         12
1297108 COLUMBIA AVE     1309610 20TH ST           3.20100         11
1299102 I94BL            1299204 PORTER ST         1.07000         11
1297110 DICKMAN ROAD     1298906 WASHINGTON AVE    3.51500         11
1297108 COLUMBIA AVE     1296603 HELMER ROAD       2.23100         10
1297309 CAPITAL          1310307 HAMBLIN AVE       7.22000         10
1297108 COLUMBIA AVE     1309403 WOODROW ROAD      3.31600         10
1298801 GOODALE AVE      1298805 LIMIT ST          0.54900          9
1297309 CAPITAL          1309601 TERRITORIAL RD    5.98300          9
1298804 W M37            1298904 KENDALL ST        0.86000          9
1298904 KENDALL ST       1298109 M 37              0.54900          9
1296603 HELMER ROAD      1309601 TERRITORIAL RD    4.01200          9
1298906 WASHINGTON AVE   1310307 HAMBLIN AVE       0.98900          9
1296303 DICKMAN ROAD     1297305 FOUNTAIN ST       3.93600          9
1297108 COLUMBIA AVE     1309501 22ND              3.09100          9
1311108 BEDFORD ROAD     1298602 JACKSON ST        0.50200          9
1297108 COLUMBIA AVE     1309604 ARBOR             3.43000          8
1299107 ELM ST           1299102 I94BL             0.58000          8
1297309 CAPITAL          1299109 UNION ST          8.26600          8
1297309 CAPITAL          1308005 KNAPP             3.02300          8
1296303 DICKMAN ROAD     1296608 RIVERSIDE DR      4.14500          8
1298703 BEDFORD ROAD     1307605 MORGAN ROAD       0.75000          8
1304001 BROOK ST         1303401 CALHOUN ST        0.00000          8
1297309 CAPITAL          1300003 WABASH ST         8.38600          8
```

FIGURE 12 Leading portion of intersection high-rank report.

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Allocating Highway Safety Funds

DAVID B. BROWN, ROBERT BULFIN, AND WILLIAM DEASON

Productivity in many governmental agencies can be greatly increased by the application of optimization techniques. As these techniques progress, it is important to keep those agencies who are using them up-to-date with the most recent innovations. Presented is an update of a highway safety application, progressing over 15 years, from the use of dynamic programming to a branch-and-bound technique. The branch-and-bound technique is faster, can handle larger sets of project data, and does not suffer from round-off errors as did the dynamic programming technique. These features have enabled the total available funds from categorical highway safety grants to be allocated to produce the maximum benefit in terms of estimated savings of lives, injuries, and property damage.

One of the primary functions of governmental authorities is the management of funds that are placed under their supervision. In order to ensure that maximum benefits are obtained from the application of limited funds, government agencies must make intelligent decisions as to which projects are to be funded and the degree of funding. This need is true whether the project area is medical research, housing for the underprivileged, or highway safety improvement. These decisions may be based on many factors such as public opinion, equity, and the mandates of higher authorities. However, all other things being equal, these decisions should be based on maximizing the total quantified benefit that can be produced from the expenditure of the available funds. Unlike other factors, economic comparisons of roadway improvement projects can be quantified for easy manipulation on the computer. Such projects range from simple warning sign upgrades to major rechannelizations and bridge repairs.

If accurate costs and benefits for each of these proposed projects are obtained, guaranteed optimal budget allocations can be generated. To obtain such accuracy, cost and benefit estimates must be made by individuals who are experienced with such projects for consistency if not perfect accuracy. Methods of assessing costs and benefits of projects have been developed and are available elsewhere (*1*). Early studies by Graham and Glennon (*2*) determined that the most important aspect of the cost assessment process is in the initial identification of high-accident locations. Many studies have determined the value of a cost-safety effectiveness approach to the allocation of funds including the works of Brown and Colson (*3*) and Bellamo et al. (*4*).

In a study by McFarland and Rollins (*5*), data from five states were used to compare three optimization techniques as applied to the allocation of highway funds. The three techniques were dynamic programming, integer programming, and incremental benefit-cost analysis. These were also compared with the simple benefit-cost method, which was demonstrated to produce less than optimal results. Budget allocations produced by the three optimization techniques were similar, and generally better than the simple benefit-cost method by 35 to 40 percent. Most important, a sensitivity analysis found that proportionate overestimation (or underestimation) of countermeasure effectiveness did not significantly affect project selection. This result is critical because relative accuracy is much easier to attain than absolute accuracy in estimating future highway safety costs and benefits.

Brown (*6*) and Brown and Colson (*3,7,8*) documented the state of Alabama Highway Department's support of the development of a software system known as Cost-Benefit Optimization for the Reduction of Roadway Environment Caused Tragedies (CORRECT). On the basis of a collection of standardized High Accident Location Investigation Forms (HALIForms), this system computes cost-benefit information regarding roadway improvement projects under consideration and derives potential budget allocations from this information. The optimization technique originally applied in CORRECT was dynamic programming, and the computer program for this algorithm is documented in the work by Brown (*9*).

Recently, a branch-and-bound algorithm was implemented to replace the dynamic programming module as the optimization portion of the CORRECT system. The branch-and-bound program is faster, can handle larger sets of nonhomogeneous data, and does not suffer from round-off errors as did the dynamic programming routine. Following is the definition of this problem and the mathematical and human-factors advantages of the branch-and-bound approach.

PROBLEM STATEMENT

Consideration will be restricted to those problems that can be addressed by roadway modifications, such as the installation of signs, lights, or the entire reconstruction of an intersection. The fact that most people are familiar with some part of the roadway system presents a unique problem in applying standard management techniques to allocating funds for safety improvements. Political expediency can have heavy influence because elected officials are in ultimate control of the public budgetary expenditures.

A perceived cause-effect mechanism influences the public and, hence, the politicians. Two catastrophic forces are currently perceived to motivate action in this arena: (a) an accident itself, and (b) legal action against public officials. The recurring question of why someone has to be killed at a location before corrective action is taken is well known.The perception is that the officials are acting only as a result of a given incident and not as a result of some comprehensive plan.

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Although this perception might be accurate in many political arenas, any comprehensive plan must begin with those locations that historically have proven to be hazardous. Public officials may well be so limited in funds that improving a location where an accident had not occurred would be incompetent on their part.

The second perceived motivator is litigation. Although some lawsuits against public officials serve the long-term good, near term they are devastating. Both the defense and the settlement are generally paid from public funds, reducing the ability of the governmental unit to use that money for improvements. Further, a paranoia develops analogous to the gun-shy dog. In the absence of a dependable method for allocating safety funds, the lawsuit-shy officials often retreat from every form of quantification. There have been cases occurring outside of Alabama where needed improvements were intentionally not made after an accident because the improvement would infer that the political unit was negligent in not making the improvement prior to the accident.

Given the legal and economic constraints under which public officials must function, how are they to approach the difficult task of budget allocation? The solution is in using the most advanced tools available. The decision maker should not turn the entire decision-making process over to a computer—this would show a misunderstanding of the capabilities and limitations of computerized tools. The process cannot be so quantified that human judgment is completely removed. The objective of the proposed approach is to provide the decision maker with the knowledge of the theoretically optimal solution, so that when compromises are made from that solution, they can be done in an intelligent manner, maximizing the overall good of the public.

Public funds should be expended in a way that maximizes the total benefit to society produced by these expenditures. The real problem lies in formulating a quantitative method of assessing the amount of benefit produced by a given set of expenditures. When a public official takes the initiative and establishes a procedure whose objective is to reach this goal, the criticism is shifted from the official to the procedure. Because allocations are not being made according to political favoritism, criticism along these lines can be easily rebutted. Critics are now duty-bound to devise a better procedure. This is unlikely, because public officials will continually improve their procedures if they are indeed striving for the overall public good. Of course, it is contingent on their communicating their processes to their constituency.

It therefore behooves public officials to use an optimization technique to allocate available funds in this sensitive area of the public sector. Heuristic approaches have the danger of omitting a needed project in favor of an inferior one, which could be legally devastating to a public official. Further, it is to their benefit, from a political and legal standpoint, to publicize the technique and allow it to be subjected to public scrutiny and criticism. Because the applied technique returns the maximum benefit, critics might be challenged to devise a solution (i.e., a set of roadway projects) that would return a higher total benefit.

Given the presence of an optimization technique, there are two major problems involved in the allocation of highway safety funds. The first is the large number of locations (intersections, bridges, etc.) to which improvements could be made. The second is the production of estimates of the cost and the benefit for each of the improvements that might be proposed once a location becomes a candidate for improvement.

Clearly all locations pose some potential hazard that could be mitigated given the availability of funds. Imminently dangerous situations require immediate action, e.g., the detour of traffic around a hazardous work zone. The objective here is to identify and evaluate those locations that are not imminently dangerous, but have reasonable potential for safety improvement.

Brown (*10*) provides the details for selecting the most hazardous locations and obtaining a cost and a benefit for each potential improvement. The procedure begins by a computer search of accident records over the last several years to provide a list of candidate locations. The data are then summarized and sent to the divisional investigation team, where engineers familiar with the location generate possible alternatives to remedy the problems. The engineers are also encouraged to add locations to the list that may not have yet had enough accidents to be included, but are considered to be potentially hazardous. An investigation of each site is conducted and standardized forms are completed that include costs as well as expected results for each alternative improvement proposed. The forms are sent to the central office for accuracy and consistency checks, and then processed by an algorithm, which generates cost and benefit data for each alternative at each candidate location.

This process, while not perfect, is defendable in that it places the key judgments involving future countermeasure effectiveness upon the local investigation experts, who are most capable of making these decisions. The similarity of projects between investigation teams assures against bias, because patterns of overestimation and underestimation can readily be detected centrally. Further, the comparison of raw data from similar projects throughout the state ensures consistency, which is the critical element in obtaining an optimal set of projects to undertake. In those cases where one local investigating team is out of line with the majority of others, corrective action is taken by the central administrator by reviewing all source data from the field. The central administrator has the authority to overrule those estimates that deviate significantly from estimates based on past experience and documented evaluations. However, in most cases the cause of the deviation is determined, and the parties negotiate estimates while being as consistent as possible with other similar projects.

At this point, the problem is to take these sets of costs and benefits for each improvement and find the set of improvements and locations (i.e., policy) that returns the maximum total benefit. Although this might seem straightforward, the sheer number of alternatives leads to combinatorial explosion. For example, if there were only 30 locations with two alternatives at each location there would be 2^{30} possible budget allocations to be considered. If 1 million allocations per second were examined by computer, it would take about 20 min to enumerate them all. However, if the number of locations were doubled, resulting in 2^{60} allocations, the same computer would take more than 365 centuries. Because a typical problem faced by the state agency would have hundreds of locations, the complexity of the problem is enormous.

To formalize this problem somewhat, let the total budget to be allocated be B. At location $j = 1, 2, \ldots, N$, let $i = 1, 2, \ldots, M_j$ denote the mutally exclusive alternatives avail-

able. Define C_{ij} to be the cost of alternative i at location j, and b_{ij} its benefit. A policy is defined to be a statement of which alternative is to be implemented at each location. Let d_{ij} be equal to 1 if alternative i at location j is funded, and 0 otherwise. Only one value of d_{ij} will equal 1 at any location j. The objective is to find the values of the d_{ij}s that produce the maximum sum of the returns. Thus, the optimal value of the total return Z is obtained by maximizing

$$Z = \sum_{j=1}^{N} \sum_{i=1}^{M_j} b_{ij}\, d_{ij} \qquad (1)$$

This objective function is subject to a total budget constraint given by

$$\sum_{j=1}^{N} \sum_{i=1}^{M_j} C_{ij}\, d_{ij} \leq B \qquad (2)$$

No more than one alternative chosen at each location is enforced by

$$\sum_{i=1}^{M_j} d_{ij} \leq 1 \qquad \text{for all } j. \qquad (3)$$

Finally,

$$d_{ij} = \text{binary},\ i = 1,2,\ldots,M_j;\ j = 1,2,\ldots,N. \qquad (4)$$

This model has the form of a multiple-choice knapsack problem (MCKP) defined in the work by Sinha and Zoltners (*11*). The knapsack problem is a special case of the MCKP, and any algorithm that can solve the MCKP can also solve the knapsack problem. Because Karp (*12*) has determined that knapsack is NP-complete, so is MCKP. Being NP-complete implies that if an algorithm is more efficient than the enumerative methods that exist for MCKP, this same algorithm can be easily modified to solve the traveling salesman problem, the job shop scheduling problem, and most other problems of interest to decision makers. Because people have searched for efficient algorithms for these problems for several centuries, it seems unlikely that they exist. Therefore, enumerative methods such as dynamic programming, branch-and-bound, or heuristic algorithms are appropriate ways to solve the problem.

EXISTING SOLUTION PROCEDURE—DYNAMIC PROGRAMMING

Dynamic programming (DP) has been successfully used to allocate highway safety funds in Alabama for the past 15 years. It has returned millions of dollars in additional benefits as demonstrated in several reports (*3,6–8*). However, the well-known curse of dimensionality affects this algorithm in the same way as it does other DP algorithms. If there are n potential projects (stages) and the budget to be allocated is B, then there must be at least nB storage locations available in the DP algorithm. The best solution must be stored for each possible value of the budget B for each of the n stages. For a typical problem with a budget of $7 million and about 60 projects, over 420 million words of computer memory would be needed. Clearly this amount is beyond the capability of the most advanced computer. Auxiliary storage such as disks could be used, but the degradation of execution time makes this solution unattractive.

Generally, it is possible to partition the budget to reduce the storage problem. If all project costs are in the tens of thousands, all costs and the budget can be divided by 10,000 to reduce the required storage. For the example previously mentioned, 4.2 million storage locations would still be needed. This is assuming that the thousands, hundreds, and tens digits are not significant. Substantial rounding error may result when large budgets are allocated between alternatives that differ significantly in their values (e.g., a signing project versus a major reconstruction of an intersection).

In order to further alleviate the storage problem, the DP algorithm was implemented iteratively. The total problem was decomposed into a number of subproblems, each containing alternatives with relatively homogeneous costs. The number of subproblems was chosen so that each budget was of manageable size. This telescoping technique yielded a range of potential budget allocations and returns for each of the subproblems. These were, in turn, used as input to a summary DP run to determine the size of each of the subbudgets (*13*).

There are two basic difficulties with this procedure. First, the results were no longer guaranteed to be optimal, because subsets of the original problem were optimized. This was not a severe practical problem because tests of the algorithm on actual data showed the results to be close to the optimal. However, the mere fact that there could be a better solution poses an ethical issue, especially in the area of safety. Second, manual intervention was required, which not only cost valuable professional time, but also introduced the possibility of handling errors. For these reasons, alternative techniques were explored for producing optimal solutions.

NEW SOLUTION PROCEDURE

Because of the drawbacks of the current DP approach, a branch-and-bound procedure was used. This was motivated by encouraging computational results reported both for knapsack problems (*14*) and for multiple-choice knapsack problems (*11*).

The branch-and-bound procedure was based on the same algorithm used to solve the knapsack problem presented by Bulfin et al. (*14*). Relatively straightforward modifications of this algorithm were made for node selection, branching rules, and generating an initial solution. Bounds were obtained by solving the linear programming relaxation of MCKP using the method discussed in the work by Sinha and Zoltners (*11*). These bounds were strengthened by Tomlin-type penalties (*15*), comparable to penalties used by Bulfin et al. (*14*). A further modification was made to force all other members of a mutually exclusive set to zero when a variable in the set was fixed at one. Details of similar algorithms are given by Bulfin (*16*) and Bulfin and Liu (*17*). Previous computational studies (*14,16,17*) indicate that budgeting 2,000-location problems with five alternatives (i.e., 10,000 variables) can be solved with relative ease. These studies also show that the solution approach is insensitive to the problem data, as long as it does not require double precision arithmetic on the computer.

The implementation of the branch-and-bound algorithm went smoothly. There was no hesitation in using the model

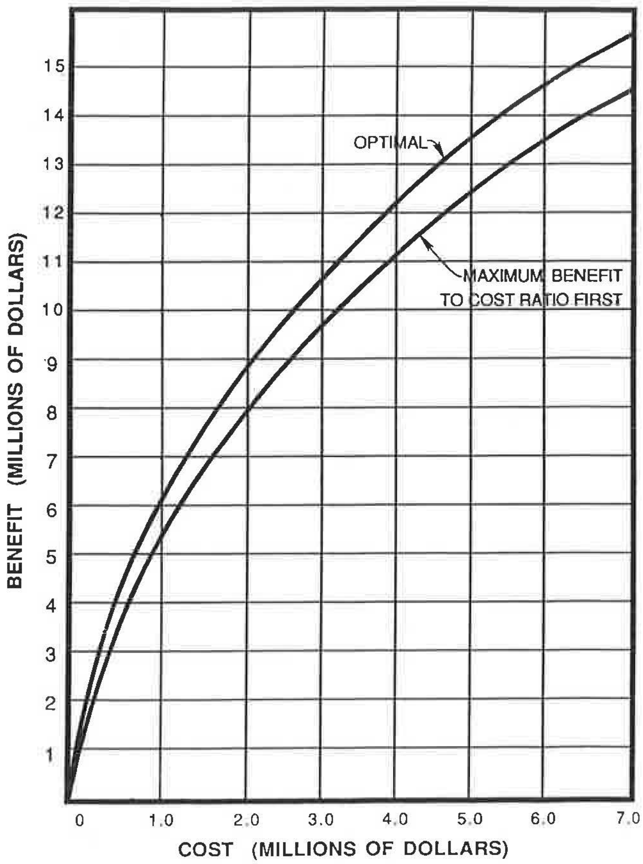

FIGURE 1 Cost-benefit curve, Section 209—Phase II.

because a similar one had been successfully used for years. The raw costs and benefits were fed directly into the computerized routine, eliminating the need for manual intervention. A comparison between the DP and the branch-and-bound solutions showed insignificant differences, confirming that the round-off errors did not cause practical problems for the highway data. The new technique was well received because of the time savings it produced in professional personnel. This amounted to approximately one person-day per run. Because some allocations required several runs, this saving was substantial. As an added benefit, a novice could use the new system as easily as the experienced user.

DISCUSSION OF RESULTS

Figure 1 shows the results obtained using the branch-and-bound technique for the first time. The optimal line shows the total benefit obtained from implementing the optimal policy obtained for each of the corresponding budgets. For comparison, another good policy (i.e., maximum benefit-cost first) is plotted for comparison. The term good is relative—it is not arbitrary and it has intuitive appeal. The original studies in Alabama determined that this policy was far superior to the unquantified policies previously employed.

Assuming that a maximum benefit-to-cost ratio first (or worse) is employed without optimization, there are significant returns at all reasonable budget levels. For example, a $4 million budget has an additional return of $1 million. This is attained at no additional cost to the taxpayer.

In conclusion, the use of optimization techniques for budget allocation has been established. It is essential that those techniques be applied that not only produce optimal results, but also are easy and efficient to invoke. In this application, the branch-and-bound technique not only guaranteed optimality, but also enabled this solution to be obtained at a great time savings.

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Emergency Medical Service Rescue Time in Fatal Road Accidents

HAROLD BRODSKY

Ambulance rescue times in fatal road accidents in the United States have improved little over the past few years. In rural areas, it still frequently takes a half-hour, or more, for an ambulance to arrive after a crash. On the average, this happens in about one out of every five fatal accidents. Ambulance rescue time consists of two almost equal components: response (or travel) time and communication time. A decrease in response time is unlikely in the future, but more could be done to reduce the time it takes to call for an ambulance. In particular, interagency delays in notification could be eliminated. A matched data set from Missouri shows that in 10 to 20 percent of fatal accidents the police delayed 5 min or more in notifying an ambulance dispatcher. Delays of this nature occur because a caller may fail to report injuries in the road accident. Perhaps an ambulance should be sent out anyway even if it is not certain that injuries are involved.

In 1988, the average ambulance response time in fatal road accidents in the United States was about 6 min in urban areas and about 11 min in rural areas. This level of accessibility is a product of more than two decades of effort on the part of federal, state, and local authorities. The goal of the Federal Emergency Medical Services Act of 1973, to blanket the entire nation with ambulance services, has largely been realized (*1*). The question that needs to be asked now is whether a plateau has been reached or whether there are still opportunities for further progress.

If ambulance speeds average about 1.5 min/mi in urban areas (40 mph) then a response time of 6 min can be equated to an average distance of about 4 mi from ambulance station to accident scene. If mile-a-minute ambulance speeds are usual in rural areas (60 mph) then the average rural ambulance station in the United States was within 11 mi of a rural road accident.

Some areas of the United States are below acceptable standards of emergency medical service (EMS) accessibility, and no doubt with better training some services may be able to reduce their response times. Nevertheless, the prospect for a major improvement in ambulance response time in the years ahead seems unlikely. Indeed, the U.S. Department of Transportation 1988 annual Fatal Accident Reporting System (FARS) indicated that neither urban nor rural ambulance response times had shown a significant change since 1982.

But is response time the only, or even the best, statistic to use to evaluate the accessibility of EMS in road accidents? Response time is defined as the number of minutes between EMS notification of an accident and EMS arrival at the scene of the crash. From the point of view of a public health administrator, response times provide useful statistics for locating or relocating ambulance services. Response times also provide performance standards that may be useful in judging the efficiency of a service station relative to others. But from the point of view of the injured, response time is only one component of total rescue time. What really matters most to the injured is the length of time it takes an ambulance to arrive after a crash.

In 1988, for the entire United States, rescue time in fatal road accidents in urban areas averaged about 12 min and in rural areas about 22 min. Rescue time, which includes communication delays, will always be longer than over-the-road travel time (or response time). Consequently, figures for rescue time will always have a more sobering appearance.

Given that a seriously injured person can go into an irremediable state of shock in 15 to 20 min, then the average rural rescue time of 22 min is still not fast enough. Police and emergency medical technicians do observe cases where the injured die during the rescue process. Time is a factor in survival, or in degree of recovery, otherwise there would be no sense of emergency when responding to a road accident.

The mathematical difference between rescue and response time is communication time. Communication time is the duration from the time of an accident to the time when the EMS dispatcher was first alerted. Communication time is often neglected because it does not fall within the responsibility of any health professional. Medical professionals are trained to deal with the injured after they arrive.

Emergency 911 operators, police communication officers, and EMS dispatchers are concerned about delays in communication, but little has been published about the problems they encounter in communication. State funding has largely been devoted to purchasing state-of-the-art electronic equipment, but the human element involved in sending unambiguous messages and in making difficult decisions under uncertainty has largely been left to the common sense of the bystanders who first call in the accident and to individual operators who must make sense out of what is frequently a garbled accident report.

Every minute saved in dispatching an ambulance is equivalent to a minute saved in response time. But of the two, communication time probably stands a better chance of improvement because it is not only a matter of technology and economics, but also a matter of procedural efficiency. Existing procedures are so varied that it is hard to imagine that much thought has been given to determining what works best. Complexity is taken for granted and therefore communication time is ignored. Consequently, national or state-

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wide guidance for dealing with certain types of troubling but recurring situations are largely nonexistent.

But how important is communication time as a component of rescue time? To answer this question, statistics are helpful, but reliance on overall averages may be misleading because communication varies with location. The key to understanding why communication delays occur is knowing where they occur.

Statistics show that between 1983 and 1988, changes in rescue time have been negligible for the United States as a whole. Any trends within states are difficult to verify because of insufficient data.

An analysis of merged police and EMS data from the state of Missouri shows that communication time actually consists of two separable components: call time and injury verification time. The distinction between call and injury verification times is more than perfunctory. Different strategies will be needed to improve each of these separable aspects of communication time.

STATUS OF EMS DATA IN FARS

The U.S. Department of Transportation has collected data on EMS notification and arrival times in fatal accidents since 1975 (FARS tapes). At first, only a handful of states were in a position to supply such data, but by 1988 the majority of states were able to submit fairly complete records. Seventeen states had reasonably complete records going back to 1982. However, certain states apparently do not have legal requirements for ambulance districts to supply trip information.

California, New Jersey, Virginia, Massachusetts, and Washington are among the states that have a large proportion of missing data, at least as of 1988. Ambulance services have traditionally been funded locally and a fierce independence often exists between local and state offices. Even where a state can gain the voluntary cooperation of a local ambulance service, a match has to be made between the records of two entirely different agencies: police and ambulance service. A correct matching of records can be difficult and expensive. In some FARS data police notification and arrival time have been found to be erroneously substituted for EMS notification and arrival time. For certain analyses, these FARS records are more than useless, they are absolutely misleading.

Why then is there a reluctance to publish figures on rescue times along with other EMS road accident statistics? Data are available from the FARS tapes for the time of the accident and for the time of arrival, only a matter of subtracting the time of arrival from the time of the accident to obtain the rescue time is involved. However, the time of accident is estimated by the police, usually by asking witnesses when the crash occurred, or by estimating the time of the crash on the basis of the first incoming call. Figures are often rounded, a sure sign that they are estimates (*2*).

Because the time of the accident is estimated it may seem less reliable than notification or arrival times, which are based on actual observation. On the other hand, police have no reason to bias their estimates of accident time because their performance, like that of EMS, is based on response time, not on communication time. Therefore, accident time averages are likely to be meaningful. But even notification and arrival times are subject to random errors because of misreading clocks, fast or slow clocks, mismatches of ambulance and police records, and clerical errors.

In 1988, there were 41,601 fatal accidents in the United States with about 58 percent in rural areas and 42 percent in urban areas. Of the 24,025 fatal accidents in rural areas, 27.9 percent were lacking data that would enable a rescue time to be calculated. In urban areas the situation was worse. Of the 17,576 urban fatal accidents, rescue time could not be calculated in 44.8 percent of the cases because these urban figures are strongly influenced by California, which alone accounts for almost 40 percent of the missing urban data. Does this missing data introduce biases in the national averages? It all depends on how the data are used. If ambulance service is no better, or worse, in California than in the rest of the United States, then this missing data may have little effect on overall national averages.

A small proportion of the remaining data were not used in this analysis because EMS notification time was given as earlier than accident time. Police may simply have underestimated accident time. On the other hand, such data may also be caused by clerical errors. Also, in a relatively small number of cases rescue time took more than 2 hr after the accident. Without a doubt, cases of this nature are real because a car can crash into a ditch late at night and not be discovered until the morning. But these data represent unusual circumstances and perhaps should be analyzed separately. In any event, including such data might strongly skew summary statistics. Accordingly, all negative rescue times and times greater than 2 hr were left out of this analysis.

COMMUNICATION TIME AS A PROPORTION OF RESCUE TIME

In urban areas, an ambulance can be expected to arrive quickly (in 5 min or less) at the scene of a crash in about one-third of the fatal accidents. In rural areas, this arrival time occurs in only about 10 percent of the cases. From another point of view, in about 1 out of 20 fatal accidents (5 percent) in urban areas an ambulance may take an unconscionable half-hour, or more, to arrive at the crash site. In rural areas, even this dismal record will be exceeded in one out of five fatal accidents (Figure 1).

However, for rapid rescues of 5 min or less, communication may be almost instantaneous. In only 25 percent of the fatal accidents where rescue was within 5 min did the communications take more than 1 min. But communication delays become a progressively greater problem as rescue time increases. In rescue times of greater than a half-hour, in half of the cases at least 21 min was required to communicate a need for an ambulance (Figure 2). Delays in communicating the need for an ambulance and delays in the length of time it takes to get out to the rural scene of an accident generally work together to exacerbate a problem that is virtually certain to result in a large number of fatalities among injured people.

Behind these dry statistics is a sense of frustration. An ambulance crew called to the scene of a distant rural accident may rush to try to save a life. What the statistics above indicate, however, is that much of the delay in the arrival of the ambulance may be due to initial difficulties in communication.

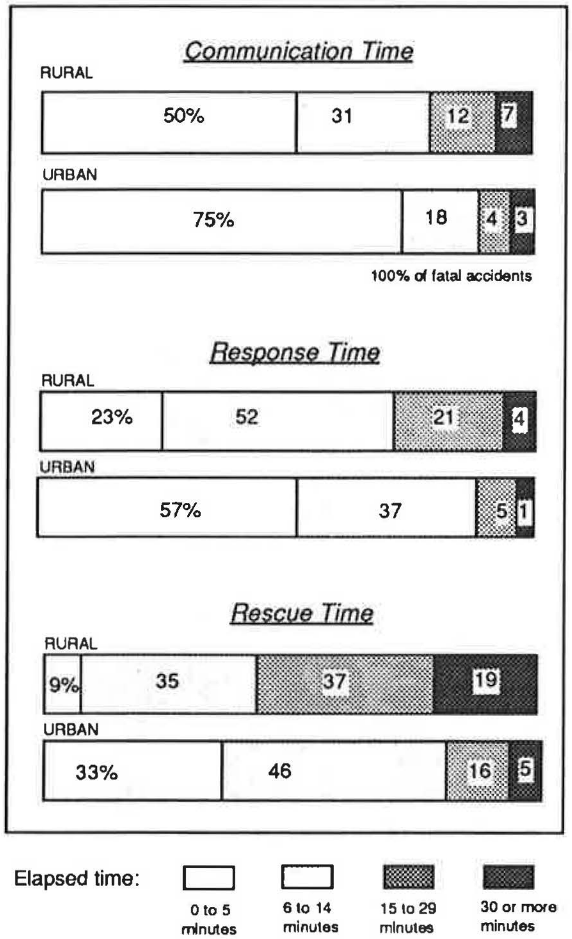


FIGURE 1 EMS communication, response, and rescue time for fatal accidents, 1988. (Source: FARS tape, 1988, based on 16,561 rural and 9,661 urban fatal accidents.)

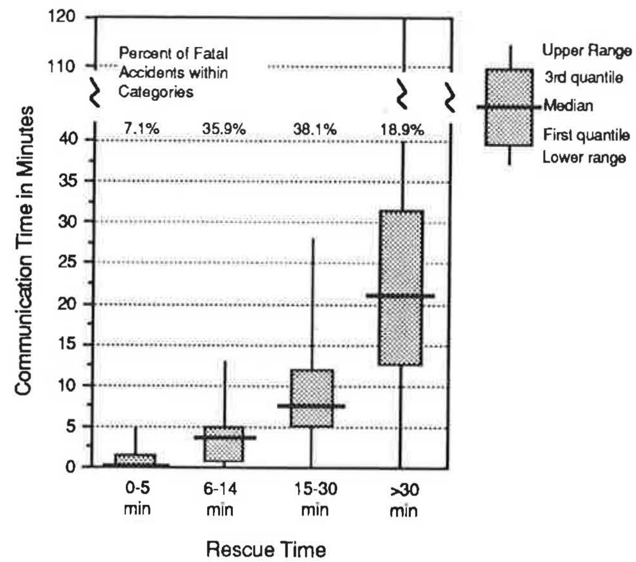


FIGURE 2 Communication as component of rescue time for rural fatal accidents, 1988. (Source: FARS tape, 1988, based on 15,334 rural fatal accidents.)

COMMUNICATION TIME AND ENVIRONMENT

Communication delays vary with the environment. Low travel densities and low land use densities next to the road will result in fewer passersby when an accident occurs. For those observing the accident, a low density may make it difficult to find a telephone to notify the authorities. The density effect can be studied by selecting relevant variables: first, the United States can be divided roughly into two discrete density regions: (a) lower density for the mountain and plains states, and (b) higher density for the remaining states. Second, a communication delay can be expected to be more likely during the late hours of the day (between 11 p.m. and 6 a.m.), than during other hours. Finally, the type of road might be examined because the more housing adjacent to a road the more likely communication will be quicker. This situation suggests that limited access highways (Interstates) would be more likely to have longer communication delays than other roads.

When data from the 1988 FARS tape are examined with each of these factors (region, hour, type of road) in mind, it appears that rapid communication (of 5 min or less) is less likely in mountain and plains states than in the rest of the United States, during late hours than during normal hours, and on Interstates than on other roads. Overall, rapid communication is also less likely in rural than in urban areas (Figure 3).

No surprises are apparent in these statistics. Indeed, if these relationships did not hold one would be inclined to suspect the accuracy of the data. Density relates to accessibility to a telephone and being close to a telephone seems to be the major factor in EMS communication delay.

EMS RESCUE TIME AND MULTIFATALITIES

In accident analysis one would like to know how many lives might be saved if certain actions were undertaken. But unless one has a perfectly matched sample it will be difficult to obtain completely convincing results. In any nonexperimental analysis a possibility will always exist that one factor or another may have been left out of consideration.

All persons in a vehicle involved in a crash are at risk of becoming a fatality. But in some accidents only one fatality will occur, whereas in others there will be multifatalities. In part, the age and health of the individuals involved in a crash will affect the probability of a multifatality accident occurring. In part, the probability will also depend on the nature of the accident. Certainly, the probability of more than one person dying in a crash will also depend on the number of persons involved in the crash. If there are four people in a vehicle when it crashes, the probability of more than one person dying, all other things being equal, will be greater than if only two persons were involved. However, the probability of a multifatality will also depend on how fast EMS arrives at the scene to render aid.

In order to verify these assumptions, 1988 FARS data for the United States were used consisting of an initial sample size of 9,381 fatal accidents in which there were exactly two persons involved in the accident. Overall, in only 5.5 percent of these two-person accidents did multifatalities (two fatalities

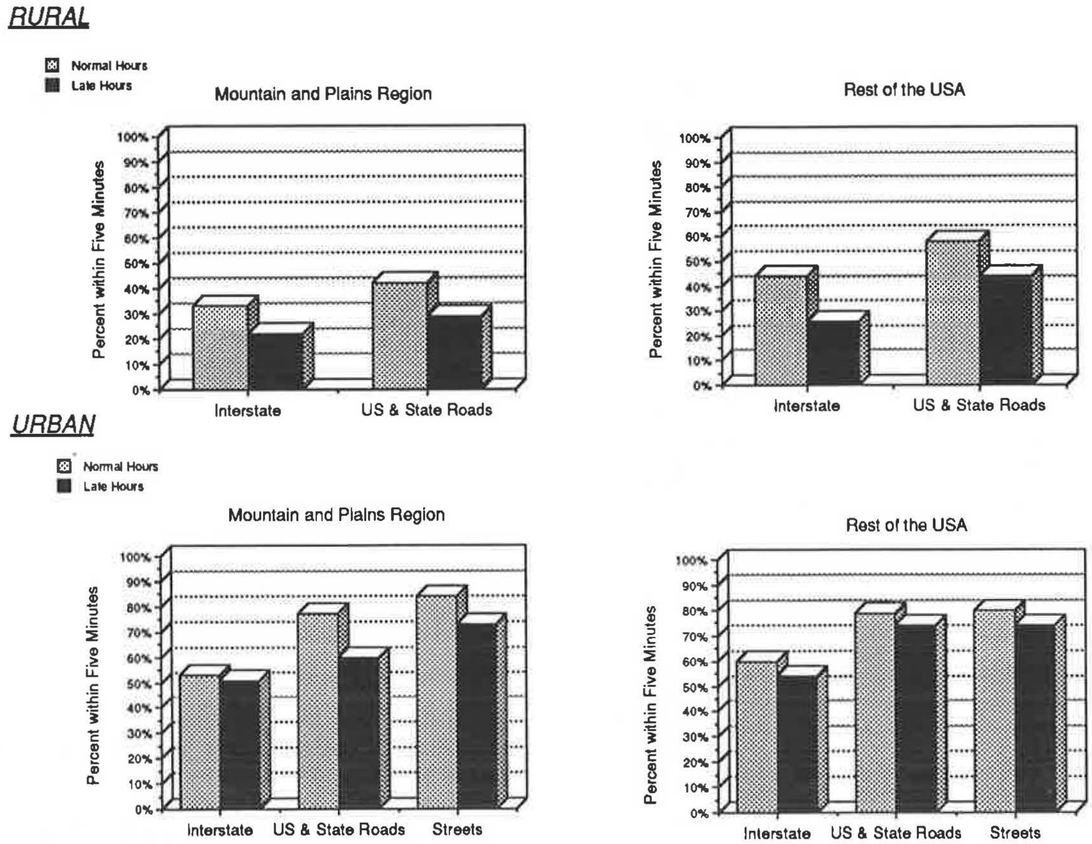


FIGURE 3 Percentage of rural and urban fatal accidents with a communication time within 5 min, by region, hour, and type of road, 1988.

in this case) occur. When broken down into groups of rescue time categories, the percent of multifatalities varied. Multifatalities occurred in 3.9 percent of cases where EMS arrived within 5 min. But the rate increased to 8.3 percent in cases where rescue time for EMS was 30 min or more. The same EMS rescue time relationship was also examined for involvement categories consisting of three-, four-, and five-person accidents with similar results. In all cases, as one would expect, multifatalities increased with involvement category. But more important, multifatalities also increased with the length of time it took EMS to make the rescue.

However, these results were based on accidents at all speeds. Speed also affects the probability of multifatalities. Further, slower speeds may be associated with locations where rescue time is faster. Therefore, it seemed reasonable to sample only those accidents where posted speed was ≥ 55 mph. When this procedure was followed, the sample size for the two-person involvement category dropped to 4,676 accidents. The overall percent of multifatalities increased from 5.5 to 6.5 percent (not a large increase, but certainly in the expected direction for increased speeds). In fact, all involvement categories (three-, four-, and five-person) showed an increase in multifatalities. Clearly, probability of a multifatality in a fatal accident increased with posted speed. However, controlling for speed did not affect the general relationship of an increase in multifatalities with an increase in EMS rescue time. Posted speed was not a confounding variable, although it could have been.

Next, pedestrian accidents were removed from the sample. For two-person involvements the sample size dropped to 3,893. Here, the underlying assumption was that although two people may be involved in a pedestrian accident, only the pedestrian will actually be at risk. Removing pedestrian accidents from the sample actually improved the relationship between speed of EMS rescue and percent multifatalities. (Removing pedestrian accidents would have had an opposite effect if they occurred more frequently in remote locations.) The variation now became 6.1 percent for rescue times of 5 min or less, and 9.9 percent for rescue times of 30 min or more. But the presence of pedestrian accidents in the original sample did not alter the general relationship between rescue time and multifatalities.

The type of accident might possibly affect the association because the risk of having more than one person die may vary depending on whether the crash was single or multiple vehicle. Consequently, the sample was reduced to multiple-vehicle crashes. Sample size now dropped to 1,913 accidents for two-person involvements. Nevertheless, the relationship between speed of rescue, number of persons involved, and multifatalities still remained (Figure 4). The validity of this association was checked for statistical significance with logit analysis. Both of the independent variables, involvement and EMS rescue time, were found to be significant at the 1 percent level.

Additional control variables such as age of persons involved and precise nature of the accident could be used to further refine the process. However, each refinement reduces the sample size and introduces the possibility that a valid relationship may be obscured by random variation.

The results as they now stand are consistent with the general understanding that speedy rescues save lives. The results may actually underestimate this effect quantitatively because some of the individuals who died in single-fatality accidents may also have been affected by delays in EMS arrival.

As in many studies of risk, no one demonstration will be sufficient. A combination of studies using different methods of standardization of risk will certainly make a stronger case for a causal relationship. In a study done in Texas, for example, the effect of EMS accessibility on fatalities was measured using a severity ratio, rather than multifatalities, as a means of standardization (*3*).

But a logical relationship between EMS rescue time and survival is not the issue because there can be little doubt about the emergency of injury road accidents. The major purpose of a statistical analysis is to provide a better quantitative assessment of the numbers of fatalities affected by variations in EMS rescue time. As the quality of the data improves, one can expect to see progressively more accurate assessments.

TRENDS IN RESCUE TIME, 1983 to 1988

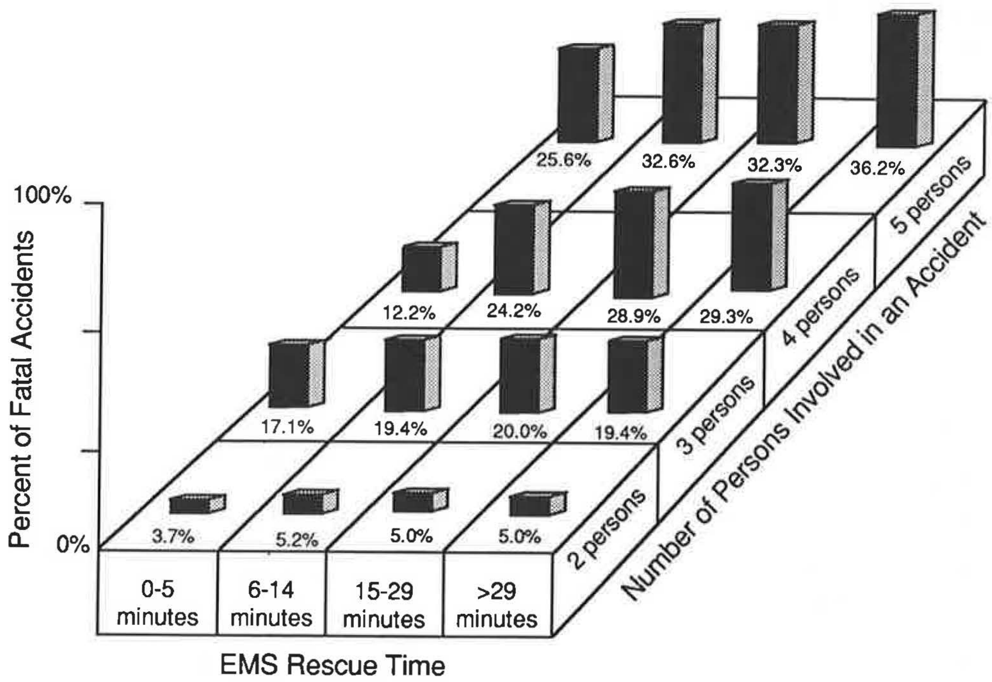
The quantity and completeness of EMS data on fatal accidents in FARS has improved since 1983. For example, in 1983 only 53.3 percent of rural rescue times in fatal accidents could be calculated. By 1988, 72.1 percent of rural fatal accidents had EMS data associated with it; only 27.9 percent were missing. But precisely because the proportion of missing data has changed, especially within certain states, it is not always possible to assume a trend. Improvement, or lack of it, may simply be caused by the effect of having more complete data.

Mapping state-by-state changes between 1983 and 1988 indicates that 20 states improved their rescue time, at least in rural areas, with respect to the percent of fatal accidents with a rescue time of 30 min or more. But 11 states showed an increase in percent of EMS rescues in rural areas that were 30 min or more (Figure 5).

No pattern is apparent in the state-by-state comparisons, and overall national statistics do not indicate significant improvements. Delays in communication time actually increased from 5.7 to 6.3 percent in fatal accidents with 30 min or more needed for communication. Response time declined slightly from 3.6 to 3.2 percent in cases of 30 min or more needed for response. Rescue time remained about the same, or slightly declined, from 7.4 to 7.2 percent when 30 min or more are needed for rescue. The static nature of communication time over the past 5 years, like the static nature of response time, might indicate that little can be done to improve rescue time, or it might indicate that the communication aspect of EMS has simply been neglected.

CLARIFYING COMMUNICATION TIME WITH MATCHED MISSOURI DATA

What is not clear from statistics based on FARS data alone is the relationship between police and EMS notification of a



Note: Fatal accidents on roads with 55 mph. or greater posted speeds and multiple vehicle accidents only.

FIGURE 4 Multiple fatality accidents as percentage of total fatal accidents by involvement and EMS rescue time. (Source: FARS tape, 1988.)

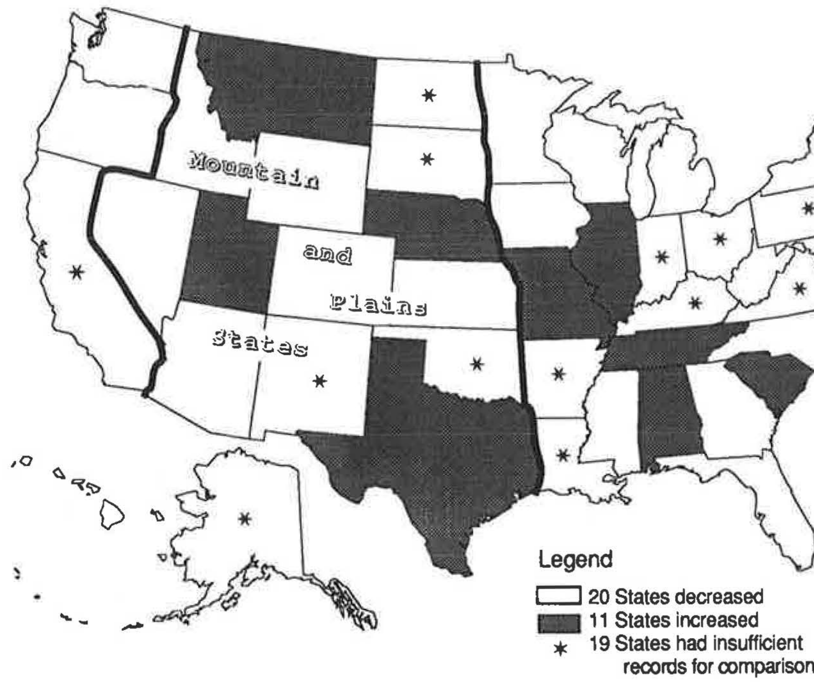


FIGURE 5 Change in percentage of rescues of 30 min or more in fatal accidents, 1983–1988. (Source: FARS tapes, 1983 and 1988.)

road accident. Who gets notified first, the police or EMS? Or do they both get notified at the same time? Are there any delays in notification between agencies? How much of communication time is from delay by a passerby in getting to a telephone, and how much is from interagency delays in transmission?

In order to answer these questions it is necessary to examine both EMS and police notification times. FARS data, unfortunately, omit police notification time, although it could have been obtained easily from the state police accident record.

The need for matching different data sources to produce a richer file of data is becoming more apparent in accident research. Daniel Fife (*4*) describes matching of FARS data with a file from the National Center for Health Statistics (NCHS). Using such criteria as age, sex, and date of death, he was able to uniquely match 85 percent of the FARS data with NCHS data to produce a data set that can examine the nature of the injury with aspects of the motor vehicle crash. Similar research in matching data files currently underway by Sandra W. Johnson in Maine is sponsored by the National Highway Traffic Safety Administration. In the Maine study, ambulance run reports are being linked with police, hospital, and other data files to produce a sensitivity index for statewide systems that will evaluate the sequence of events from time of crash to hospital release of the injured.

In this study, EMS data were taken from the FARS tapes for 1985 to 1988 and matched with data from Missouri police injury accidents. The FARS data include the time at which EMS was called as well as location date and time of accident. Location and time of accident make it possible to match the FARS file with the police file relatively easily. For example, in the 1987 fatal accident data it was possible to match 918 out of 927 fatal accidents. The unmatched nine either had missing or incorrectly coded records. Among the 918 successful matches, some required a small change in the coding. For example, a set of six observations was incorrectly coded in FARS by the county, which was obvious because no counties in Missouri have that digit. Usually, computer consistency checks made with the FARS data are comprehensive, but this particular data set was not checked for valid county codes.

All times were converted to minutes from the beginning of the day to enable simple subtractions to be made. Because there is only one date on the records, a day was added to the subtraction when the rescue times went past midnight. Adjustments were also made when it was clear that military time was not used.

Data from the fatal accidents demonstrate that most frequently both police and EMS are notified at about the same time. In urban areas, police and EMS are notified within 1 min of each other in 41.7 percent of the fatal accidents. In rural areas, the figure is less, only 27.0 percent of fatal accidents. Most rural areas in Missouri do not have 911 emergency numbers, so the caller has to call either the police or EMS. However, what is most disturbing is that in urban areas in 14.7 percent of the fatal accidents EMS was notified 5 min or more after the police had been notified. In rural areas, the percentage increased to 19.9 percent of the fatal accidents (Figure 6).

Police are apparently not always notified first. In urban areas in 15.1 percent of the fatal accidents, EMS was apparently notified more than 5 min before the police. In rural areas, the figure was apparently 19.3 percent. Apparent is used, but the figures for EMS notification before the police are ambiguous. Police notification indicates the time that the officer who filled out the accident report was notified, not necessarily the time that police were first informed of the accident. If a police officer is too occupied with the accident to be able to fill out an accident report another officer may

be called on to do this job. The officer who arrives later will record the time he or she was notified of the accident on the accident report. Consequently, some, many, or possibly all instances where the police were apparently notified after EMS become clouded. In some cases, EMS could really have been notified before the police but there is no way of knowing this for sure without access to the original police logbooks.

But why the delay in police notifying EMS? When the police receive a call they always ask about injuries. If the caller indicates that there are injuries, then the police immediately radio the EMS dispatcher for an ambulance. However, if the caller is vague then the police may hesitate until confirmation that an injury is involved before they notify EMS. Consequently, in 15 percent or more of the fatal accidents there may be a delay of at least 5 min because the police are unsure about injuries.

This component of communication delay is well known to both police and EMS communications operators and there

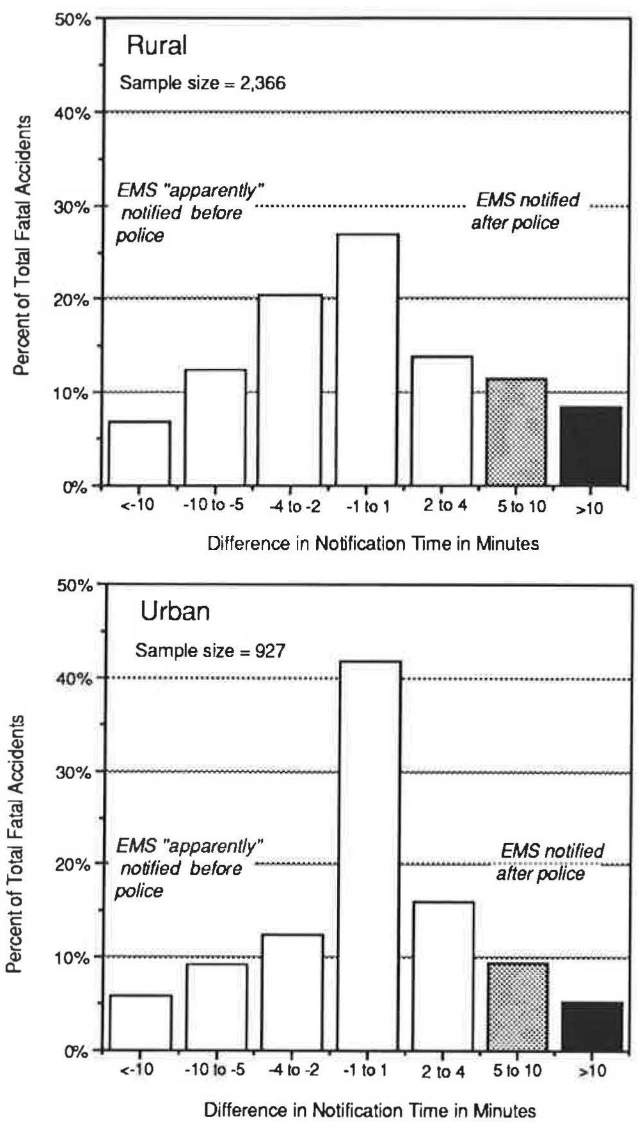


FIGURE 6 Police minus EMS notification time versus percent of fatal accidents, Missouri, 1985–1988.

are considerable differences in opinion as to what, if anything, can be done about it. Because the vast majority of reported accidents do not require an ambulance and because fatal accidents are comparatively rare occurrences even among accidents that do require an ambulance, there is a tendency to perceive this problem as minor. Only when a statistical analysis is done for an entire state over a period of 1 year or more do the serious dimensions of this problem begin to emerge.

Some EMS people are of the opinion that the EMS dispatcher should be notified of a road accident, regardless of whether the police think that an injury is involved or not. This practice would place more of the responsibility on EMS for deciding whether or how to respond. EMS dispatchers would then have to decide whether the description of the crash warranted an ambulance rescue. Perhaps EMS should be sent out more frequently to road accidents even when it is uncertain that an injury is involved. The extra burden that this might place on an ambulance service could best be understood by people within the service and might be a factor in decision making.

If a change in policy is initiated, it should be monitored over time to weigh increases in successful rescues against probable increases in dry runs (no transportation of injured persons). At present, no state has a program for evaluating the causes and consequences of delays in emergency communication in road accidents.

CONCLUSION

Although ambulance response time is the most widely used statistic in evaluating EMS, it is meaningful only when making performance comparisons between otherwise similar services. A much more important statistic is rescue time.

From the time of the crash until the time EMS arrives, the injured may suffer irreversible physiological changes affecting survival or complete recovery. Therefore, the faster the ambulance arrives the more likely the individual will recover. The results presented are consistent with an understanding that delays in EMS arrival do affect the number of fatalities.

Rescue time in road accidents has changed little over the past several years. Response time will likely remain frozen at its present level unless additions are made in the number of ambulance stations, which could be costly. Communication time may be more promising to pursue for improvements in the accessibility of EMS in road accidents.

Communication time is a major component of rescue time, about equal in importance to response time. Communication delay occurs in situations where it is difficult to find a telephone. The effect of travel and population densities on communication time is quite clear. However, new technologies involving use of satellites and cellular phones may in the future reduce this problem (*5*). Encouragement should be given to the development of this kind of technology for its potential value in medical emergencies.

But another aspect of communication delay is quite independent of telephone availability. Apparently, not all incoming calls to the police clearly specify the need for an ambulance, and most car crashes do not result in injuries. Consequently, the police generally do not notify EMS about an accident unless they are sure that injuries are involved.

Police communications officers assume the primary responsibility for sorting out road accidents likely to need EMS from those that probably do not. But, in about 15 percent or more of fatal accidents, the communications officer makes the wrong decision by failing to notify EMS immediately. Should this responsibility of sorting things out be shifted to the EMS dispatcher? And if EMS is allowed to make these decisions, what policy should EMS use? Should EMS automatically respond to all reported accidents, or should EMS wait for confirmation of actual need as the police usually do? Or is there a middle ground that has yet to be explored?

Police and EMS are separate agencies that are often reluctant to examine controversial boundary issues unless drawn to it by external pressures. The general public is probably unaware that this problem even exists. But communications officers know that their judgment could be questioned in court. Negligence has been brought up in other situations, but never in connection with EMS delays in road accidents. However, for good reasons both the police and EMS operators record all incoming calls.

Statistical results from the Missouri data on differences in agency notification are dealt with in greater detail by Brodsky (*6*), but the kind of analysis presented here could be repeated in most states. Missouri has a communication system similar to many others in the United States. Therefore, it is likely that delays in EMS rescue in road accidents because of communication problems will be found to be widespread in this country and perhaps in other nations as well.

ACKNOWLEDGMENT

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Validation of Vehicle Stability and Control Simulations

G. J. HEYDINGER, W. R. GARROTT, J. P. CHRSTOS, AND D. A. GUENTHER

A methodology for validating computer simulations of physical systems is applied to vehicle stability and control simulations. Validation is defined, within some specified operating range of the system, as a simulation's predictability of system responses' being able to agree with actual measured system responses within some specified level of accuracy. The method uses repeated experimental runs at each test condition to generate sufficient data for statistical analyses. Acquisition and reduction of experimental data and the processing path for simulation data are described. Usefulness of time-domain validation for steady state and slowly varying transients is discussed. Importance of frequency domain validation for thoroughly validating a simulation is shown. Both qualitative and quantitative methods for comparison of simulation predictions with actual test measurements are developed. In order to illustrate the validation methodology, experimental testing of four different vehicles was performed. Comparisons between actual test measurements and simulation predictions are shown.

During the past 30 years, substantial effort has gone into development of numerous vehicle stability and control computer simulations. Unfortunately, much less effort has gone into answering the important question of the validity of these simulations. Because experimental testing of full-scale vehicles for validation procedures is quite expensive and time consuming, many vehicle dynamics simulations have had little or no validation work performed. Many modified and new simulations have been compared with predictions from existing simulations as the sole check of their validity. Others have been experimentally substantiated only for limited vehicle operating conditions and then assumed to be valid for all other operating conditions.

NHTSA desires a vehicle stability and control simulation that can simulate a wide range of light vehicles (passenger cars, pickup trucks, vans, and utility vehicles) in a broad range of cornering and braking maneuvers. NHTSA is studying existing simulations, selecting the most appropriate one for its purposes, and improving it to resolve problems identified during the selection process. Simulation validation methodology and procedure described were developed as part of this work.

For a particular application, the validation methodology described can distinguish the most appropriate simulation out of a group of simulations. In addition, it has proven itself to be useful for identifying measurement errors in simulation parameters. In the modification and improvement stages of simulation development, the procedure can be used to identify specific problem areas of a simulation model.

Validation methodology can be used to validate a variety of vehicle dynamics simulations besides the stability and control types discussed, which includes simulations dealing with vehicle rollover and ride quality. This methodology can also be extended and used for validating computer simulations of many other types of physical systems.

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BACKGROUND

Validation work using full-scale vehicle test results has been performed for several vehicle stability and control simulations developed during the past two decades.

One simulation for which substantial validation efforts were made is the Highway-Vehicle-Object Simulation Model (HVOSM) (*1*). This simulation was originally developed in the late 1960s and has matured through several versions to its present form. It includes general three-dimensional motions resulting from vehicle control inputs, traversals of terrain irregularities, and collisions with certain types of roadside obstacles.

HVOSM predictions were compared with experimental results for various handling and accident maneuvers. Although the validation work appears adequate for steady state conditions, little attention appears to have been paid to transient responses. Validation work in the frequency domain does not appear to have been performed. However, it does appear that some adjustment of vehicle parameters to better match simulation predictions to experimental vehicle responses did occur.

Two modified versions of the HVOSM simulation, the Hybrid Computer Vehicle Handling Program (HVHP) (*2*) and the Improved Hybrid Computer Vehicle Handling Program (IHVHP) (*3*) were implemented in the early 1970s at the Applied Physics Laboratory of the Johns Hopkins University. Principal modifications were addition of a steering system model and removal of obstacle impact dynamics. In 1979, a revised version of these simulations was implemented at the University of Michigan as the Improved Digital Simulation, Fully Comprehensive (IDSFC) (*4*). This simulation was used in the current research.

For validation purposes, predictions of the HVHP, IHVHP, and IDSFC simulations were compared with vehicle field test data for several handling maneuvers. Validation of these simulations, as with the previous versions of HVOSM, paid little attention to the transient response regime. Validation work in the frequency domain was not performed. As a result, the

simulations' poor performance in predicting transient behavior was never identified. Finally, vehicle parameter measurement techniques that were available to the researchers were not accurate. As a result, adjustment of vehicle parameters to better match vehicle responses occurred, making the entire validation suspect.

In the mid-1980s, Systems Technology, Inc. (STI), developed the Vehicle Dynamics Analysis Nonlinear (VDANL) simulation for analyzing vehicle lateral and directional control and stability (*5*). This simulation differs from the preceding ones primarily by its suspension and tire models. It was validated by comparison with vehicle field test data for several handling maneuvers (*6*). The maneuver matrix used by STI was not extensive enough to provide simulation validation for the full range of vehicle operating conditions of interest to NHTSA. In addition to simulation validation in the time domain, STI performed validation in the frequency domain that involved comparison of experimentally measured yaw rate to handwheel steering angle frequency response functions (magnitude and phase angle) with simulation predictions. During validation of this simulation, some adjustment of vehicle parameters to better match vehicle responses occurred. The STI simulation was also used in the current research.

The preceding cases are typical of simulation validation work in the literature. In most cases, there was insufficient testing to cover all maneuver regimes of interest. In addition, little attention was paid to the transient maneuvers or the frequency domain. Because of parameter measurement problems, there was a strong tendency to adjust vehicle parameters to make simulation predictions match experimentally measured vehicle responses.

WHAT IS SIMULATION VALIDATION?

Mathematical models of physical systems, such as vehicle stability and control simulations, are valid when, within some specified operating range of a system, the simulation's predictions of system responses of interest to specified inputs agree with the system's actual physical responses to the same inputs within some specified level of accuracy. This definition contains several important points.

First, in general, simulation predictions will only be correct within some portion of the system's operating range. An example of this is that vehicle dynamics predictions may be correct for low lateral acceleration maneuvers, but become progressively worse as lateral acceleration increases and nonlinear effects become more important.

Similarly, simulation predictions may only be correct for inputs that predominantly contain (following Fourier decomposition) frequencies within a specified range. Many vehicle dynamics simulations are valid for steady state and slowly varying input conditions but have problems with fast transients that contain high frequencies.

This last point illustrates why simulation validation needs to be performed in both time and frequency domains. Validation in the time domain demonstrates that the simulation can correctly predict steady-state conditions and that nonlinear effects are properly modeled. However, high-frequency transient phenomena are difficult to study in the time domain. The effects of increasing input frequency on the correctness of simulation predictions are best determined through frequency domain studies.

A second significant point in the definition of simulation validation is that simulations are valid only for specified groups of inputs and outputs. For example, in a vehicle stability and control simulation, because the simulation has been shown to be valid for braking and steering control inputs does not imply that response to a road disturbance will be correctly predicted.

The third significant point of whether a simulation can be considered valid depends on how much simulation predictions can acceptably vary from actual test results at a given operating point. The degree of accuracy required to classify a simulation as valid depends on intended uses of the simulation and the level of accuracy believed to be attainable. If only the trends of the response of a physical system are to be simulated, with little interest in predicting values, much less accuracy is required than when trying to predict exact values.

Determination of the amount of disagreement between a simulation's predictions and actual test measurements that is allowable while still having a valid simulation is difficult. One limit on attainable accuracy is that the accuracy of simulation predictions cannot be shown to be better than the repeatability of experimental measurements.

Every experimental measurement contains random error superimposed onto the signal. Random errors are defined as transducer measurement noise, unaccounted for variations disturbing the system's inputs, and random minor changes in the system. For vehicle testing of the type discussed, random error would include the effects of wind gusts, road roughness, tire nonuniformity, and brake changes from test to test. Other sources of experimental nonrepeatability include, for example, variability in control inputs.

Some disagreement between simulation predictions and experimental measurements will be caused by random error. Because the simulations studied here cannot predict random error, if simulation predictions agree with experimental measurements to within the experimental random error the simulation should be considered valid.

The easiest way to determine the experimental random error level present in data is to repeat all experimental runs multiple times. Given data from several tests, statistical procedures can be used to calculate random error levels.

Two important points about simulation validation not in the previous definition are

1. The parameters used to describe the physical system to a simulation must be measured independently—not from the experiments that obtain simulation validation data, and
2. While validating a simulation, parameters describing the system to a simulation must not be varied from their independently measured values to improve the accuracy of a simulation's predictions.

If either condition is not met, then a simulation is not actually being validated. Instead, the researcher is showing that by adjusting one or more parameters, curves can be generated to match experimental data. This process is not always unique because there may be several ways to change parameters to make simulation predictions match experimental measurements. This type of validation tells nothing about the ability

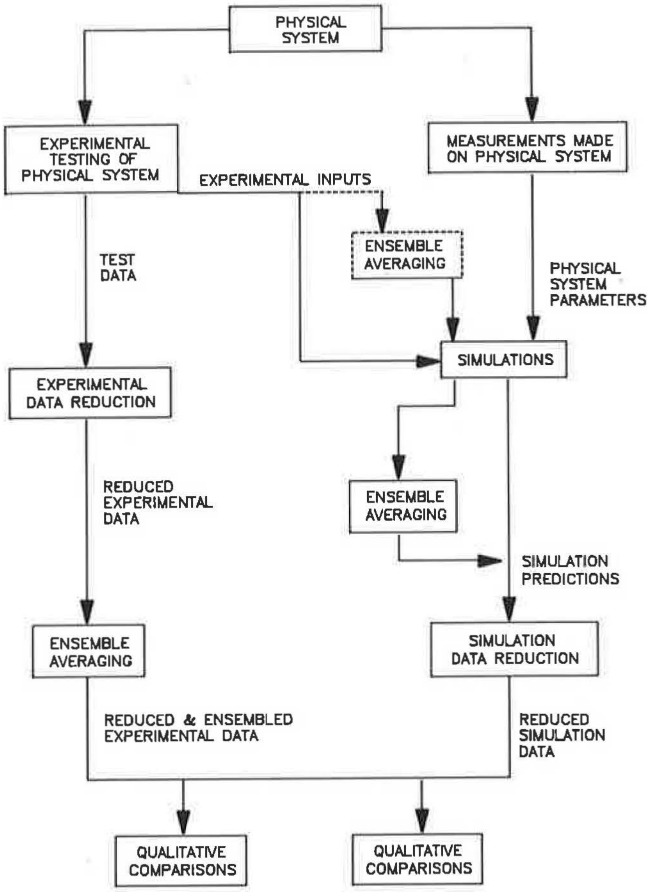

FIGURE 1 Simulation validation process data flow.

of a simulation to predict system performance when experimental data are not present.

SIMULATION VALIDATION METHODOLOGY—GENERAL CASE

The basic steps in the methodology are shown in Figure 1 as a block diagram. These steps indicate the general stages required to validate a computer simulation of a physical system. However, the steps shown are not entirely mandatory because specific details of data processing are unique to individual research programs.

Simulation validation involves the flow of information through two processes, the experimental and the simulation processes.

The experimental process begins by obtaining, via experimental testing, reliable measurements of behavior of the physical system. In order to obtain a measure of the random error present, and to improve reliability of experimental results, repeat runs of each test are made.

Physical system responses of interest must be appropriately measured and recorded. Usually, the inputs or forcing functions used to excite the physical system must also be recorded. Inputs are then used to drive simulations during validation. In some cases, system inputs are predetermined and sufficiently well defined and need not be measured.

Typically, experimental test data require a data reduction stage. This stage usually includes transforming measured electrical signals into engineering units and digital filtering. Other data reduction operations that might be performed at this point include Fourier transformation of data into the frequency domain, computation of experimental quantities that cannot be measured directly, and subsampling of data to reduce the size of data files.

The next step in the flow of experimental data is ensemble averaging the repeated test runs. This step involves computing mean values as a function of the independent variable (time or frequency) for each response of interest. It also allows the use of statistical methods to compute a measure of experimental repeatability at 95 percent confidence intervals of the mean values. The result of this step is reduced and ensembled data (consisting of mean values and confidence limits) from the experimental testing of the physical system.

Next, the flow of information through the simulation process is considered. A simulation is an analytical model of a physical system that requires parameters to represent the physical system. These physical system parameters, such as mass or inertia, damping, compliance, geometry, etc., must be measured (or estimated when necessary) and supplied to the simulation model.

For a simulation to most accurately predict a specific physical behavior, it must be driven with the same inputs as the physical system. These driving inputs must be known (or measured) for each run to be simulated.

The validation methodology presented is based on analyses of data from repeated experimental runs. In general, a simulation should be driven by separate, measured, inputs from each run, followed by ensemble averaging of simulation predictions. This process corresponds to the case shown in the block diagram with solid lines.

However, from a practical point of view the procedure is time consuming and expensive. Although the correct procedure is to ensemble average following simulation, if individual inputs from repeated experimental runs are sufficiently alike and a simulation is not highly nonlinear, inputs may be ensemble averaged before they are fed into a simulation. The predictions obtained should closely approximate the means obtained by ensemble averaging the simulation predictions from separate runs. This process corresponds to the blocks with dotted lines shown in Figure 1.

Once the simulation predictions have been obtained, simulation data reduction may be necessary. This stage may include Fourier transforming the data to the frequency domain or subsampling data to reduce data file size. The result is reduced simulation data.

On completion of these steps, experimentally measured, reduced, and ensemble-averaged test data are compared both qualitatively and quantitatively to reduced simulation data. Qualitative and quantitative comparison schemes vary depending on the nature of the physical system and simulation. Some combination of both qualitative and quantitative comparison, as in this study, usually provides the most thorough validation.

The qualitative comparison scheme used in the current research consists of overlaying plots of experimental mean and simulated values versus an independent variable (time or frequency). The 95 percent confidence limits of the experi-

mental mean are also plotted to indicate experimental variability. Researchers can then observe the agreement between simulation predictions and actual measured data.

Quantitative comparison schemes include the comparison of computed steady state gains, response times, peak response times, and percent overshoots from time domain data. Frequency response comparisons include peak frequencies, peak amplitude ratios, and bandwidths. Other methods involve the use of statistical methods for comparing simulation predictions with experimental mean values and confidence intervals.

VALIDATION OF VEHICLE STABILITY AND CONTROL SIMULATIONS

A goal of the current research was to develop a vehicle stability and control simulation that can simulate a wide range of vehicles and be valid for a broad range of crash avoidance maneuvers. The first step in the research was to study two existing vehicle stability and control simulations, namely the VDANL and IDSFC simulations. Simulation validation methodology presented was developed for use during this study to find areas of disparity between these simulations and field test results. Once problem areas have been identified, simulation model improvements can be implemented to reduce simulation disagreement. This work is expected to result in a more accurate (for the operating conditions and maneuvers of interest) vehicle stability and control simulation than any developed for NHTSA to date.

Four vehicles used in this research were significantly different in size, shape, and design function. They were a 1987 Ford E–150, standard-sized van, a 1987 Ford Thunderbird midsized passenger car, a 1987 Hyundai Excel small passenger car, and a 1988 Suzuki Samurai utility vehicle.

EXPERIMENTAL DATA COLLECTION AND PROCESSING

The experimental data collection and processing portion of Figure 1 that was actually performed for the four test vehicles is shown in Figure 2.

Each vehicle was tested using several types of maneuvers covering a broad range of crash avoidance situations. Five major types of vehicle maneuvers were studied: constant speed J-turns, braking in a turn, double lane changes, straight line braking, and sinusoidal sweep steering. This last maneuver was used to study the frequency domain response of each vehicle.

For each of these maneuver types, 2 to 18 specific test cases were run. Each case was run at a different severity level or speed. For example, for straight-line braking tests cases were run with nominal deceleration levels of 0.2, 0.4, and 0.6 *g*, and at the maximum deceleration achievable by the vehicle without wheel lockup. In addition, for maneuvers involving turns cases were run with both right turns (positive lateral acceleration) and left turns (negative lateral acceleration).

Ten repeat runs were made for each test case. Six of these runs were selected for further analysis. Runs were selected for analysis to minimize the range in test speeds at the start

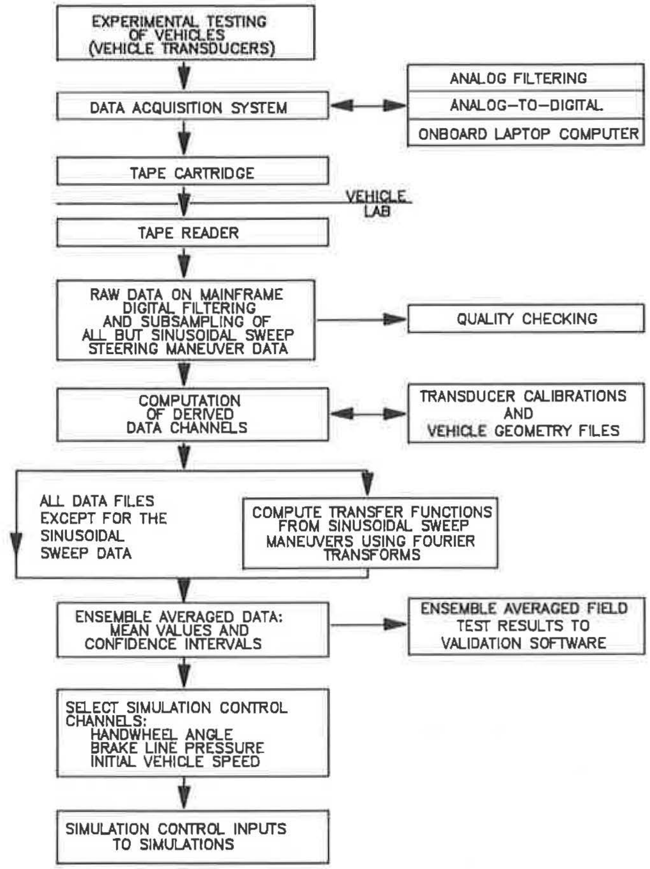

FIGURE 2 Experimental data flow.

of the runs. In most instances, all 10 test runs were performed at initial velocities within ±1 mph of the nominal test velocity. However, for some test cases several individual run initial velocities deviated too much from the nominal value; these runs were not included in any further analysis.

A total of approximately 40 cases with approximately 400 individual test runs were completed for each of the test vehicles.

Each test vehicle was instrumented to measure control inputs and vehicle outputs that were expected to provide useful comparisons with simulation predictions. This method resulted in the installation of 29 transducers per vehicle. Transducers used included linear and rotary potentiometers, tachometers, pressure gauges, angle and rate gyroscopes, accelerometers, and torque dynamometers. These devices were mounted to provide direct measurement of such quantities as vehicle sprung mass; lateral, longitudinal, and vertical accelerations; vehicle yaw rate; sprung-mass pitch and roll angles; vehicle speed; front and rear brake line pressures; handwheel steering angle and torque; suspension motions; roadwheel steering angles; and angular velocities.

Output signals from the in-vehicle transducers were amplified, filtered, digitized, and stored on tape by a Megadac 2210C digital data acquisition system. Data were transferred to a VAX computer in which all subsequent processing was done.

Next, the data were reduced by converting into engineering units, and quality checking was performed to look for trans-

ducer or data collection errors. Data were then digitally filtered to 3 Hz to reduce high-frequency noise and decimated to reduce the size of the data files. Data analyzed in the frequency domain, i.e., data from the sinusoidal sweep steering maneuver, were neither decimated nor filtered.

As shown in Figure 2, the next step in data reduction was the computation of data channels derived from the original data channels. Derived data channels are system responses of interest that cannot be measured directly by transducers mounted in the vehicle but must instead be computed from original, measured data channels. For example, experimental longitudinal wheel slips are not easy to measure directly. However, these wheel slips can be computed from wheel angular velocities and forward velocity of the vehicle.

Next, the vehicles' frequency response (transfer) functions were computed from sinusoidal sweep maneuvers. Sinusoidal sweep steering maneuvers were performed by sweeping the steering input in a smooth manner from the lowest to the highest frequency physically attainable by the driver while maintaining a generally straight vehicle path.

Along with frequency response functions, coherence functions (a function that indicates system noise and nonlinear system behavior) were also computed. For the frequency response functions found during the current research, the coherence functions are near unity (a value of unity indicates noise-free, linear, system behavior) except in frequency ranges in which the amplitude ratios exhibited very low magnitudes. In these ranges, poor coherence is expected because little system response is present so that even a small amount of random error dominates the measured signal. Although nonlinearities are accounted for in the simulation models, the high coherence values indicated that during the sinusoidal sweep steer maneuvers used to generate the frequency domain results the vehicles were being operated in a mostly linear manner.

The next stage in experimental data processing was ensemble averaging the reduced test data. For the purpose of simulation validation, the repeatability of experimental measurements must be known. This benchmark is achieved by making repeated experimental runs of each test case and using ensemble averaging and statistical methods to analyze data from repeated runs.

For test results being analyzed in the time domain, each data channel's mean values are computed for each increment of time.

Figure 3 shows typical measured lateral acceleration data and the mean value of the data and 95 percent confidence limits on the mean value. These data are from the six selected runs of a -0.2-g lateral acceleration, constant-speed, J-turn test case performed at a nominal speed of 25 mph. Figure 3 has magnified scales to make run-to-run variability easily visible. For each time increment, the distribution of the channel variables about some population mean value is assumed to be a normal or Gaussian distribution. Computing the mean from six repeated runs has a smoothing effect on the experimental data because random spikes caused by, e.g., electrical noise or road surface irregularities, become less pronounced after averaging.

At the completion of ensemble averaging, the experimental data have been processed to the point where the data can be used for simulation validation. Two ensemble-averaged chan-

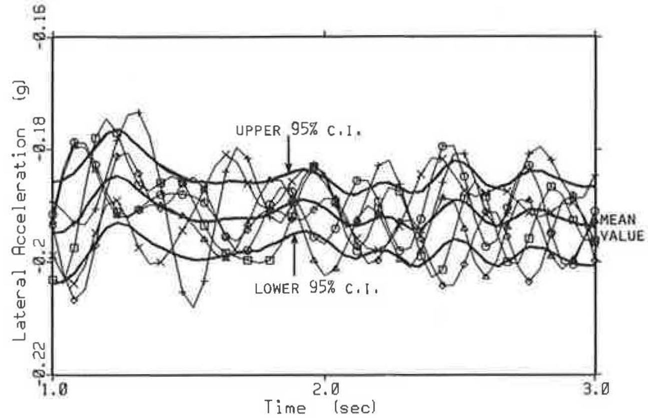

FIGURE 3 Steady state lateral accelerations from six repeat vehicle test runs and their mean value and 95 percent confidence intervals for the mean value.

nels, front brake line pressure and handwheel angle, along with average initial vehicle speed, are used as control inputs to the simulations.

SIMULATION DATA PROCESSING

The first stage in simulation data processing is vehicle parameter measurement. All vehicle simulations must be supplied with physical system parameters that describe the particular vehicle being simulated. These parameters vary from simulation to simulation, but typically include vehicle geometric and inertial properties; component inertial properties; suspension-kinematic, damping, and stiffness properties; tire force generation properties; and brake torque generation properties.

Adjusting of one or more parameters to improve simulation predictions is tempting in simulation validation. This type of parameter adjustment is ill-advised if the goal of validation is to determine the predictive capability of the simulation. Rather, the validation process should be used to identify possible errors in parameter measurement techniques.

Specialized test machines were used to measure, for each vehicle, the parameters required by the two simulations. NHTSA's inertia parameter measurement device (*7*) and small parts inertia rig were used to measure inertial properties of entire vehicles and of selected components, respectively. The suspension parameter measurement device (*8*) was used to measure suspension-kinematic, compliance, and Coulomb damping parameters. Data obtained from manufacturers was used to find shock absorber properties. Braking characteristics were measured using NHTSA's road transducer plate (*9*). Finally, tire parameters were measured by Calspan Corporation on its flat-belt tire tester (*10*).

Following completion of vehicle parameter measurement, the actual simulation runs were made. Inputs required by the simulations were vehicle parameters and control inputs from the experimental program.

Both simulations were run in open-loop control mode (no driver feedback) with control inputs being read from the ensemble-averaged mean-value channels. One exception was the sinusoidal sweep steering maneuvers. For this case, it was

decided that mathematically generated control inputs would be fed into the simulation instead of using experimental time histories. Frequency response curves generated from mathematically generated inputs demonstrate no appreciable differences when compared with curves produced from experimental inputs, but result in a savings of time and ensure that sufficient input signal power is present throughout the input frequency range of interest.

Data reduction was mainly performed by modifications that were made to the actual simulation codes. These modifications involved computing vehicle accelerations that could be directly related to the accelerations measured by in-vehicle accelerometers.

For sinusoidal sweep steering maneuvers, one other data reduction operation was performed—computation of simulated frequency response functions from simulation output.

Because the simulations were driven by the mean ensemble-averaged control inputs, no further ensemble averaging was necessary. At this point, the simulation predictions were ready for comparison with the reduced and ensemble-averaged experimental data.

QUALITATIVE SIMULATION VALIDATION

The qualitative validation methods use graphs overlaying results from both simulations (VDANL and IDSFC) and experimental data to determine simulation validity. Graphs are prepared showing simulation predictions overlaid with the mean and 95 percent confidence level of the mean of the experimental data for each channel to be compared for both time and frequency domain data.

The first priority in validating a simulation is to check its ability to predict steady state gains and transient behavior during simple maneuvers. Only after this check has been satisfactorily completed should a simulation be checked against more complex maneuvers that are meant to duplicate real-world driving scenarios (lane change, braking during a turn, etc.). Both time and frequency domain data should be used to see the full range of vehicle responses.

Graphs of constant-speed J-turn maneuvers provide a good way to check steady state gains. Figure 4 shows the vehicle's yaw rate and sprung-mass roll angle. Comparison of simulation output with experimental data should be made after transient behavior has died out. The yaw rate graph indicates that both simulations do a good job of predicting steady state yaw rate gain for this maneuver at this severity level.

The graph of sprung-mass roll angle shows that the predictions of both simulations have considerable errors. Because the vehicle's roll moment is driven by lateral acceleration (at steady state, lateral acceleration is related to yaw rate), which has been predicted accurately, and because roll stiffness values for both simulations were computed from the same vehicle measurement data, the roll moment modeling of both simulations appeared to be in error.

When validating a simulation's ability to predict vehicle behavior, it is important to avoid chasing cross talk between vehicle responses. That is, the value of a particular response may be strongly influenced by values of other responses. For example, the force input for sprung-mass roll results from lateral acceleration. If the simulation is not doing a good job

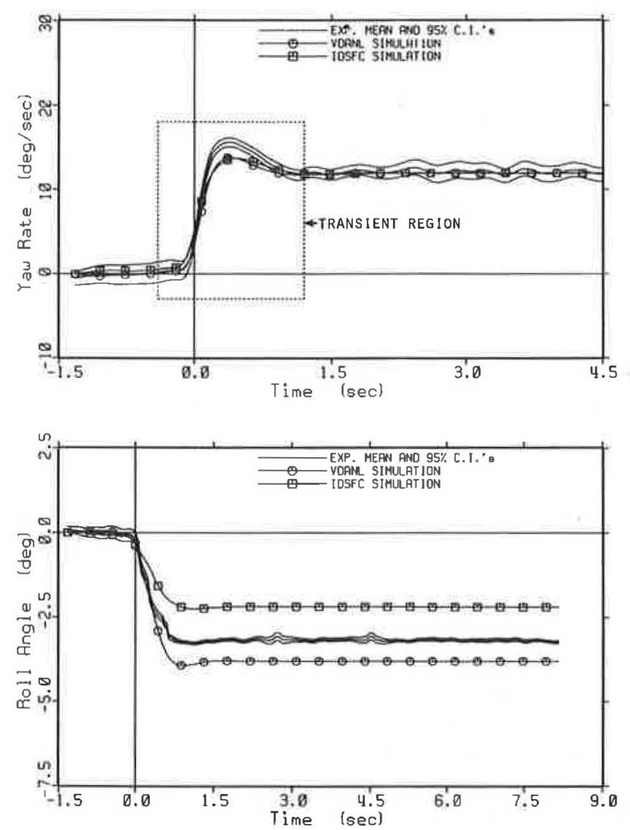

FIGURE 4 Yaw rate and sprung-mass roll angle for a 50-mph constant-speed J-turn (1987 Hyundai Excel).

with lateral acceleration in a particular frequency range, it will directly affect roll dynamics. Therefore, there is no point in looking at roll mode correlation until lateral acceleration problems are resolved.

This same approach of visually comparing time domain graphs can be carried out for longitudinal acceleration and other channels. Comparisons should be made over the entire operating range of interest because the simulation may show good agreement in the linear operating range ($<0.3\ g$) but have problems for limit maneuvers. This condition would indicate more work is necessary in the modeling or parameter measurement of the tire and suspension nonlinearities.

Once steady state responses are being accurately predicted, predictions of transient responses can be checked. A good view of a simulation's ability to predict vehicle transient behavior is given by plotting frequency response curves. For this research, frequency response curves were generated from sinusoidal sweep steering maneuvers. Figure 5 shows yaw rate frequency response (magnitude and phase angle) to steering wheel angle inputs.

Figure 4 shows that both simulations do a good job of predicting yaw response for this vehicle for this J-turn maneuver. The simulations' steady state responses are excellent, whereas examination of the transient region reveals only slight discrepancies. The yaw rate frequency response curves (Figure 5) contain differences between predicted and measured yaw rate response. The frequency at which the peak magnitude in the frequency response occurs and the magnitude of this peak highlight discrepancies that were not as apparent when examining time domain responses. Both simulations

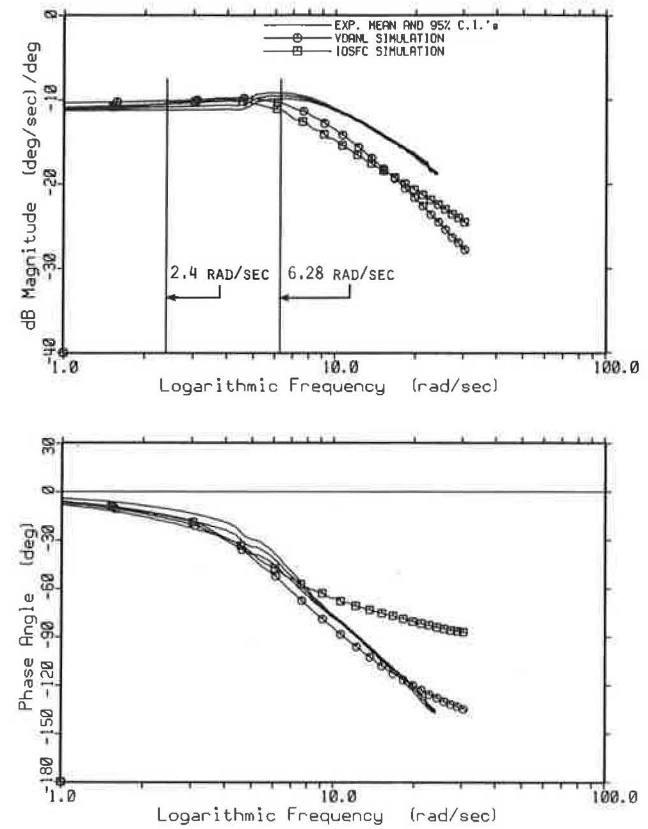

FIGURE 5 Yaw rate frequency response (magnitude and phase angle) from a 50-mph sinusoidal sweep steering maneuver (1987 Hyundai Excel).

predict low values for peak yaw rate frequency and both simulations exhibit more efficient yaw rate damping than is experimentally measured. Some of the other vehicles, especially the Suzuki Samurai (see Figure 6), show a large peak in yaw rate magnitude at the yaw rate peak frequency. If the magnitude and frequency of this peak are not predicted properly, then the transient response of the vehicle cannot be simulated accurately.

Too often, researchers have overlooked differences in the transient region of vehicle response by examining only time domain data. Errors in the transient region of time response results may be small for some maneuvers, but large for others, depending on the shape and speed of the steering (or other) input. This result is the reason why it is important to study several different types and severities of vehicle maneuvers and vehicles before claiming full-fledged simulation validity. This example indicates again the importance of generating frequency response curves, because they provide a great deal of information about system behavior.

Once steady state gain and frequency response predictions of the simulation have been validated, the simulation can be checked against maneuvers designed to simulate real-world driving conditions. The following discussion, which uses a lane change maneuver as an example, demonstrates the problems of trying to infer validity of a simulation at one operating condition from its performance at another.

Figure 7 shows vehicle yaw rate for a 50-mph lane change. Both simulations do a good job of predicting yaw rate for this maneuver. The predominant handwheel input frequency of this test is approximately 2.4 rad/sec (0.4 Hz). The ability to simulate vehicle response in this frequency range is influenced primarily by steady state predictions. Given the steady state predictions shown in Figure 4 and frequency response predictions at this frequency shown in Figure 5, it follows that simulation predictions for this lane change maneuver should be good. However, the lane change maneuver could have been designed differently and required a handwheel input frequency of 6.28 rad/sec (1 Hz), for example. Figure 5 clearly shows that the simulated response would not agree nearly as well as at the lower frequency. For a simulation to be valid for crash avoidance research, it must simulate with reasonable accuracy maneuvers likely to occur in crash avoidance situations. This validity test means a simulation should accurately predict vehicle frequency responses for any input drivers can generate.

QUANTITATIVE SIMULATION VALIDATION

In order to supplement the qualitative validation methods presented, quantitative validation methods provide significant insight into the vehicle modeling process. The method presented involved determining values, called "metrics," from simulation output and experimental data for direct comparison. Besides aiding the validation process, metrics also can be used to aid in quantifying vehicle performance by providing

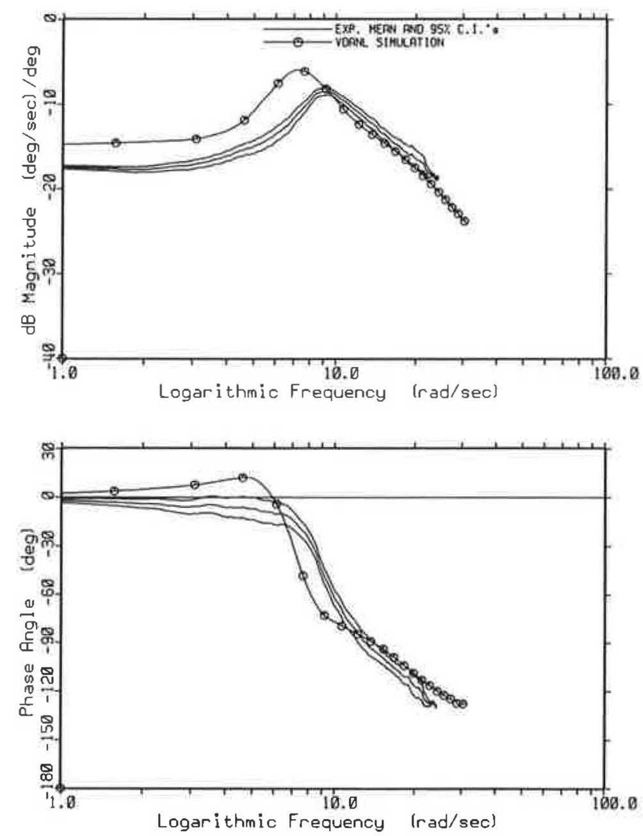

FIGURE 6 Yaw rate frequency response (magnitude and phase angle) from a 50-mph sinusoidal sweep steering maneuver (1988 Suzuki Samurai).

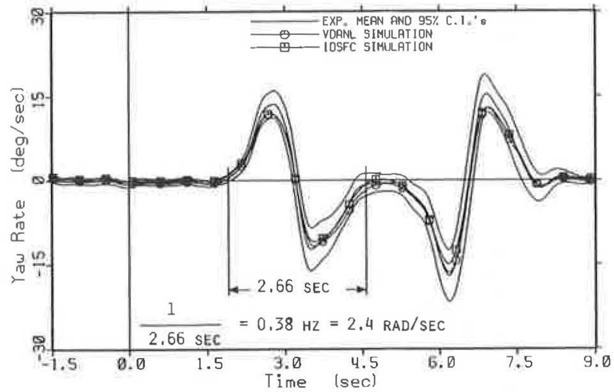

FIGURE 7 Yaw rate for a 50-mph right lane change maneuver (1987 Hyundai Excel).

direct measures of characteristic vehicle responses. Metrics are obtained both from time and from frequency domain data and are helpful, like the qualitative method, in locating and differentiating parameter and modeling problems.

The first set of metrics are derived from time domain data of pseudo-step steer, constant speed, and J-turn maneuvers. Steady state gain, response time, peak response time, and percent overshoot are standard time domain performance specifications. These specifications, as they relate to vehicle stability, have been presented and discussed previously by Nisonger and Fancher (*11*). Metrics can be computed for any of the experimental and simulated vehicle response channels with the selection depending on the intended application. In this program, lateral acceleration, yaw rate, and sprung-mass roll angle were the channels thought to be most important.

Table 1 presents yaw rate to handwheel angle steady state gains for all four vehicles while performing a constant-speed J-turn at a nominal lateral acceleration level of $+0.4\,g$. Mean values and corresponding 95 percent confidence intervals for the mean values are presented for experimentally measured gains, as are both VDANL and IDSFC simulation predicted gain values. Two different test speeds, at 25 and 50 mph, are presented.

Gains for the Ford Thunderbird are low for both simulations and at both speeds. Also, both simulations predict similar values, suggesting that a parameter common to both simulations is in error. In this case, the parameters defining steering system compliance are in error because they were measured without the power steering operating.

Measured yaw rate gains for the Suzuki Samurai show a trend opposite to the other three vehicles, i.e., the experimental yaw rate gain decreases with speed. As presented in Table 1, the VDANL simulated values do not reflect this trend. (The IDSFC simulation does not model vehicles, such as the Samurai, with solid front axles.) The reason for this discrepancy is that the Samurai has large steering system free play that the VDANL model does not model. When a steering system model including free play was added to the VDANL simulation, it resulted in correct predictions of this trend.

Time domain metrics, response time (T_r), and peak response time (T_p) are speed-of-response criteria that provide an indication of vehicle stability and, hence, controllability. Increased response time (sluggish vehicle response) as maneuver severity increases indicates decreased vehicle stability that may indicate a vehicle will be difficult to control in a high-severity, accident avoidance maneuver (*11*).

Response time and peak response time are defined relative to a reference time, the time at which the input reaches 50

TABLE 1 YAW RATE TO HANDWHEEL ANGLE STEADY STATE GAINS FOR NOMINAL +0.4-*g* LATERAL-ACCELERATION CONSTANT-SPEED J-TURN MANEUVERS [(deg/sec)/deg]

Vehicle	Experimental Mean and C.I.	IDSFC Simulation	VDANL Simulation
25 MPH			
1987 Hyundai Excel	0.219 ± 0.002	0.209	0.211
1987 Ford Thunderbird	0.203 ± 0.004	0.155	0.162
1987 Ford E-150 Van	0.125 ± 0.002	0.121	0.111
1988 Suzuki Samurai	0.162 ± 0.002	**	0.167
50 MPH			
1987 Hyundai Excel	0.302 ± 0.004	0.289	0.285
1987 Ford Thunderbird	0.224 ± 0.011	0.162	0.156
1987 Ford E-150 Van	0.156 ± 0.004	0.164	0.132
1988 Suzuki Samurai	0.140 ± 0.003	**	0.167

** The IDSFC simulation does not model vehicles with solid front axles.

percent of the steady state level. This time is used because the input is not a pure step or ramp and therefore does not have an easily measured starting or ending time. Response time is the time from the reference time to the time when the vehicle output reaches 90 percent of steady state value. Peak response time, which is only defined for responses that exhibit overshoot, is defined as the time from the reference time to the time when vehicle output reaches the maximum value of its first peak.

Percent overshoot (O_p) is a relative stability criterion. Because road vehicles behave as high-order systems, standard analysis techniques on the basis of second-order system behavior cannot be used to compute standard second-order system response parameters such as damping ratio for the total vehicle system. However, percent overshoot can be used instead of damping ratio to provide a metric related to vehicle damping and thus stability.

A second group of metrics can be derived from frequency domain data. Important frequency domain metrics are peak frequency, peak amplitude ratio, and bandwidth. These metrics are computed for yaw rate, lateral acceleration, and roll angle frequency response data. Again, as with time domain metrics, a road vehicle is a high-order system and the metrics computed are not standard second-order system parameters but are merely a means to quantify vehicle response and to provide a method to directly compare simulation predictions with experimental data.

The frequency domain metric, such as peak amplitude ratio, gives a measure of effective damping, with a higher value indicating a less damped response. For yaw rate frequency response data, if a vehicle has a high peak amplitude ratio it may become difficult to control if excited near its peak frequency. This situation, which could arise in a rapid lane change maneuver and lead to loss of control, emphasizes the importance of having good simulation predictions in the transient region. If simulation predictions for peak frequency or peak amplitude ratio are off, predictions for maneuvers, which excite frequencies near the peak frequency, will be wrong and may lead researchers to incorrect conclusions.

The final frequency domain metric, bandwidth, is defined as the frequency at which the magnitude drops 3 dB below its steady state magnitude. Bandwidth metric is a system speed-of-response measure; a wider bandwidth indicates that vehicle response characteristics will be maintained up to a higher input frequency.

CONCLUSION

A methodology for evaluating vehicle dynamics simulations by comparing simulation predictions with experimental data was presented. A general definition of simulation validation was given followed by a presentation of the steps involved in processing experimental and simulation data. Use was made both of qualitative and of quantitative comparison methods.

A methodology for simulation validation using repeated experimental runs was presented. Ensemble averaging was used for computing mean values and confidence limits on the mean values for experimental data both in time and in frequency domains. This statistical procedure had a smoothing effect on data by reducing random error in the measured signal. Ensemble averaging also safeguards against isolated measurement errors associated with data collection problems, transducer malfunction, etc. Errors of this type can go undetected if just a single experimental run is made. The validation methodology also indicated the importance of using several different vehicles as well as an assortment of maneuver types and severities.

The benefits of analyzing experimental and simulated vehicle behavior in the frequency domain were demonstrated by examples. Frequency domain results provide a great deal of information, some of which may not be revealed through time domain analyses. Transient response characteristics were examined using comparisons in both time and frequency domains.

Simulation predictions were qualitatively compared with experimental results in both time and frequency domains by plotting predictions, experimental mean values, and experimental confidence intervals on the same graphs. In addition to qualitative comparisons, quantitative comparison metrics such as steady state gain, response time, percent overshoot, peak frequency, and peak amplitude ratio were suggested.

Several possibilities resulted from this simulation validation process. A simulation may be deemed valid for predicting the particular physical system behavior that it was designed to model. The validation process may be used to select the best simulation, from a group of more than one, for a specific research project. If the simulation validation process is used to check validity of a fairly complicated simulation, most likely certain aspects of the simulation will result in good predictions whereas other aspects will not yield accurate predictions. In these cases, the simulation validation methodology presented provides a valuable tool for modifying and enhancing a simulation. Areas of simulation disagreement with experimental results can be recognized. Also, possible vehicle parameter errors and experimental data offset or calibration errors may become apparent during the validation process.

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Low-Cost Part Task Driving Simulator Using Microcomputer Technology

R. W. ALLEN, A. C. STEIN, B. L. APONSO, T. J. ROSENTHAL, AND J. R. HOGUE

Low-cost desktop personal computers and bus-compatible expansion cards have sufficient capability for the implementation of part task driving simulators. A simulation that provides a roadway scene display, sound effects, and automated orientation and training features is described. A simulator application for long-haul truck driver fatigue is also summarized.

The role of driving simulators for research and training is steadily increasing. Advanced driving simulators including motion bases are available (*1*,*2*) and future designs have been proposed (*3*). However, the significant cost of these advanced, high-fidelity simulators will limit their use to a few key research facilities. Because of the relatively low cost of ground vehicles and typical instrumentation, the change from full-scale applications to the widespread use of driving simulators will require modest cost considerations. Low- to moderate-cost driving simulators have been used in the past (*4*–*8*) and have proven successful. Low-cost simulators use microcomputer technology found in desktop personal computers (PCs).

Microcomputer technology, which is developing at a rapid pace, is currently capable of supporting a range of simulator applications. Main processors have powerful computational capability and speed and when combined with math coprocessors provide significant speedup in numerical applications typically required for simulations. A range of bus-compatible expansion cards are also available for the IBM PC-compatible computers that permit complex visual displays and sound effects. Software capability, including development tools and run-time performance, is quite advanced for MS–DOS applications.

The general approach for simulation development on the IBM PC-compatible computers has been described by Allen et al. (*9*). This approach was used in the development of a part task truck-driving simulation to measure the effects of driver fatigue. General simulator design, capability, and a specific application were also summarized.

BACKGROUND

Visual, motion, proprioceptive, and auditory feedback cues are all important to driver performance in real-world driving. Visual and auditory cues are the least costly to provide and well within the capability of current microcomputer technology (*9*). Proprioceptive cues related to control actions are somewhat more expensive to simulate because force-feel systems require electrical, mechanical, hydraulic, or pneumatic systems for simulating control force-feel characteristics. In addition, full-body motion cues are typically quite expensive to provide because they require powerful actuator devices to move the cab environment. There is also some question about the efficacy of motion cues in military simulators (*10*), and high-fidelity simulators in general seem to induce simulator sickness (*11*,*12*). Thus, a lower-fidelity, fixed-base simulator may have some additional virtues in addition to low cost, particularly in applications requiring extended exposure.

Microcomputer technology can meet all of the driving simulation functional requirements for visual and auditory feedback, as discussed by Allen et al. (*9*). Driver control inputs (i.e., steering, throttle, and brake) are processed by a vehicle dynamics model, which computes vehicle angular and translational motions. On the basis of a set of visual and sound transformations, these vehicle motions are then presented to the driver through visual and auditory displays. Numerical algorithms required for the vehicle dynamics mathematical model and the display transformations can be handled adequately by the microcomputer's main processor and math coprocessor. PC bus-compatible expansion cards for visual displays and sound are available that will process display information and drive displays on the basis of simple main processor commands.

SIMULATOR DESIGN

An overall block diagram for the PC-based part task driving simulator is shown in Figure 1. The simulator uses an 80386 computer that allows sufficient computational speed to permit a reasonable compromise between update rate and complexity. Control actions are accommodated with an analog/digital (A/D) expansion card that accepts inputs from steering, throttle and brake potentiometers, and turn indicator and horn switches. Additional A/D channels will permit future expansion of control inputs. Steering, throttle, and brake signals are processed by the vehicle dynamics model that computes variables for driving the visual roadway display scene. Transformations are applied to three-dimensional (3–D) objects in the roadway scene to create a driver's perspective as displayed on a roadway scene monitor.

A block diagram of the simplified vehicle dynamics mathematical model is shown in Figure 2. Vehicle yaw rate is assumed to be directly proportional to steering wheel angle,

Systems Technology, Inc., 13766 South Hawthorne Boulevard, Hawthorne, Calif. 90250.

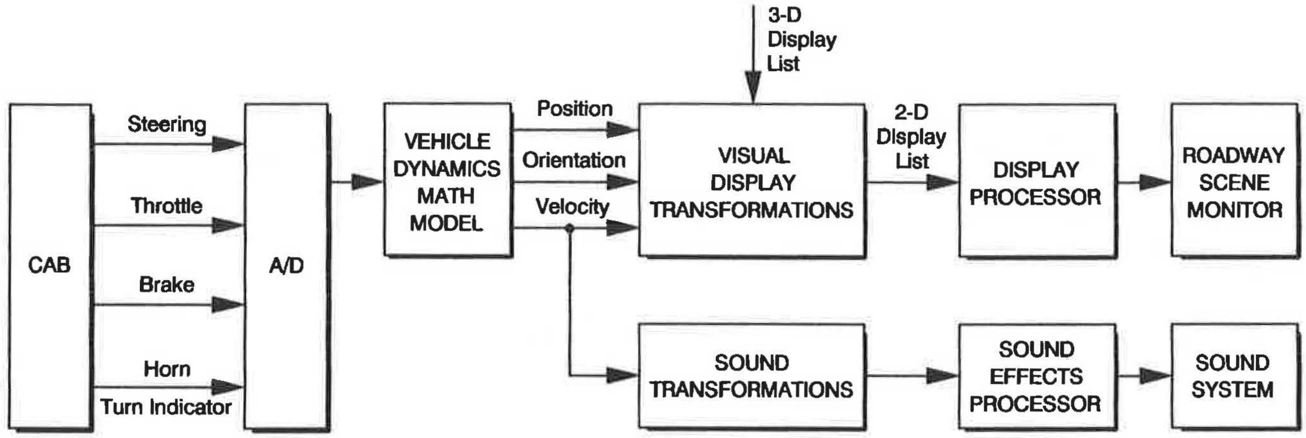

FIGURE 1 Simulator block diagram.

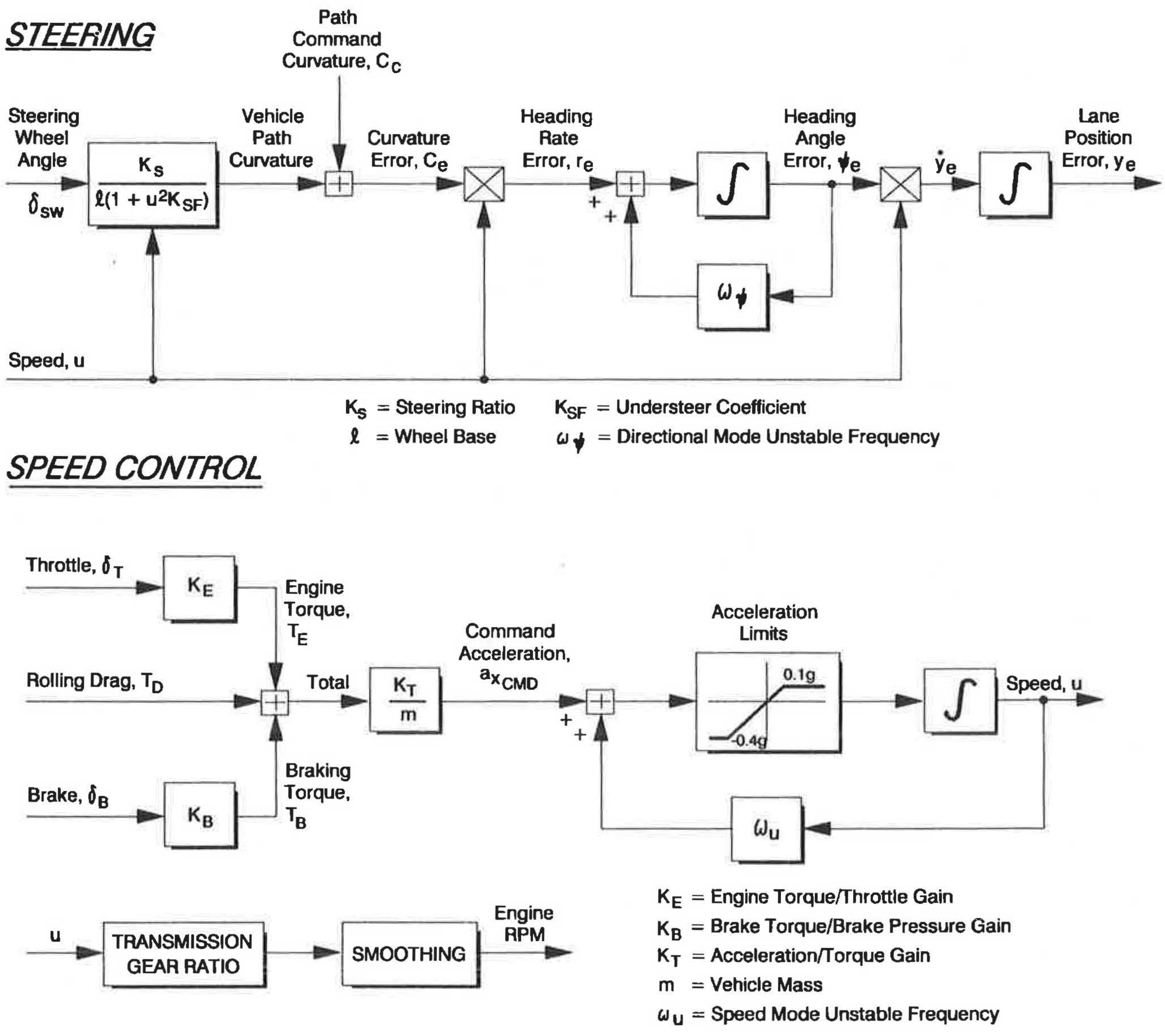

FIGURE 2 Simulation vehicle dynamics mathematical model for truck driving application.

with a scale factor associated with the vehicle Ackerman steer ratio and understeer coefficient. Vehicle yaw rate typically lags behind steering inputs because of directional (yaw) mode dynamics and tire lags. For this application, the combined computer and display system update delay as perceived by the driver was assumed to be equivalent to the delay associated with the vehicle's directional dynamics. A positive feedback is included around the yaw rate integration to simulate the effects of road crown and allow a calibrated instability to be included in the steering dynamics. Instability keeps the steering task active so that meaningful performance can be measured without resorting to arbitrary disturbances. Steering workload task can also be varied in a calibrated manner by setting the level of this instability (*13*).

Longitudinal, or speed control, dynamics assume that engine thrust is proportional to throttle opening within engine limits specified as maximum acceleration and deceleration capability. Gear ratios are simulated for a five-speed automatic transmission. Engine revolutions-per-minute commands are sent to an expansion sound effects card that creates a complex frequency engine sound with periodicity proportional to engine speed. Positive feedback instability is also included in the speed control dynamics to keep the speed task active for performance measurement purposes and to provide an additional source of workload. Vehicle speed drives a speed indicator at the bottom of the roadway display.

Display transformations process 3–D objects in a display list, as shown in Figure 3, to yield a perspective roadway scene. Simplified display transformations used have been described previously (*14*). The 3–D data base is not constrained by a physical map. Instead, the display list is object oriented, and a scenario definition module takes instructions from a scenario file to define objects that appear in the driver's field of view. Objects can be moved independently of one another in the field of view to permit traffic interactions. Objects or events (e.g., signal timing) in the scenario file can be accessed as a function either of time or of distance down the road. The time function is important as it allows control of event timing for decision making situations (e.g., whether or not to stop when a traffic signal changes from green to yellow). Time dependence of events is also necessary for experiments where exposure time is a primary variable.

Typical examples of roadway scenes are shown in Figure 4. Roadway scenes are composed of full-color polygons defined by the display transformations applied to the 3–D data base. Roadway markings, signs, and intersections move toward the driver as a function of speed. The speed of approaching and lead vehicles can be controlled independently of the simulated vehicle's speed. Vehicles, signs, and intersections can be commanded to occur through instructions programmed into a driving scenario file. The roadway display also includes a subsidiary side view mirror response task that is included as a divided-attention or workload task. The appearance of arrow or horn symbols, controlled by the driving scenario file, commands the subject to respond by activating the turn indicator (right or left as appropriate) or horn, respectively. A horizontal indicator at the bottom of the roadway display screen functions as a thermometer bar speedometer that is commanded by vehicle speed as computed in the vehicle dynamics mathematical model.

Performance measures are currently mechanized for steering, speed control, and divided-attention (horn and turn indicator) tasks as follows:

Steering Control

- Standard deviation about the mean for steering activity—the variability of steering wheel rate.
- Standard deviation about the mean for curvature error—the driver's variability in tracking behavior.
- Mean lane position—the average location of the center of the vehicle within the lane.
- Standard deviation about the mean for lane position—the variability of the preceding measure.

Speed Control

- Standard deviation about the mean for throttle activity—the variability of throttle rate.
- Mean vehicle speed—the average speed of the vehicle throughout the measurement period.
- Standard deviation about the mean for vehicle speed—the variability of speed.

Side View Mirror Task

- Mean response time—the average response time to the divided-attention task.

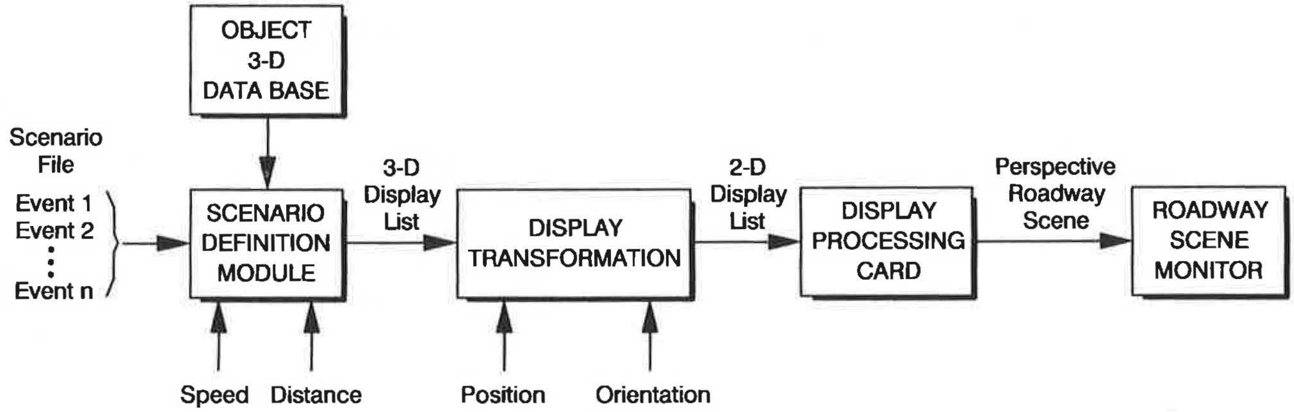

FIGURE 3 Roadway scene display processing.

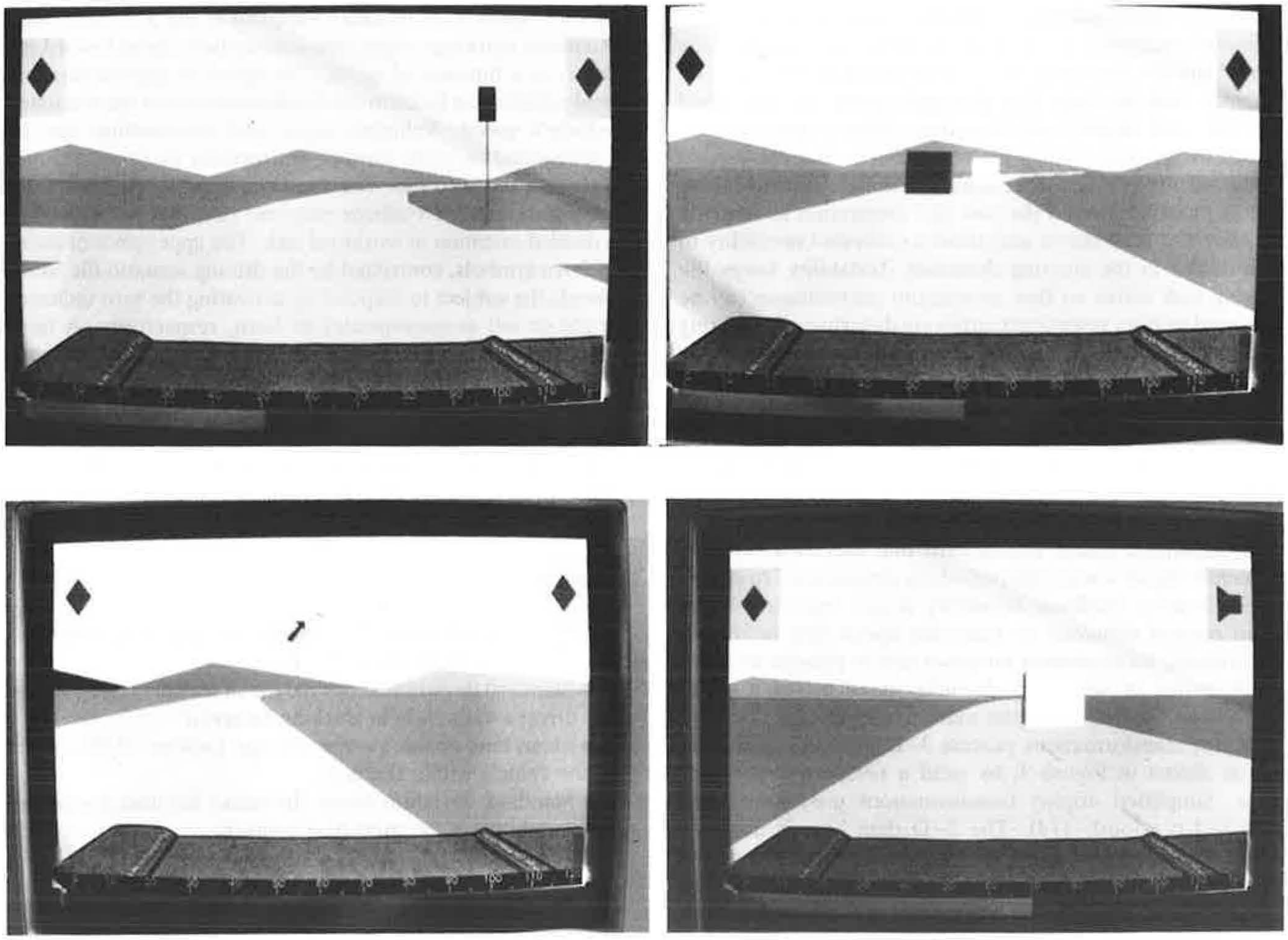

FIGURE 4 Typical roadway display scenes: intersections (*top left*), interactive traffic (*top right*), signing (*bottom left*), and subsidiary task "horn" command (*bottom right*).

- Standard deviation about the mean for response time—the variability of the preceding measure.

Steering and throttle activity measures are related to traditional reversal measures (e.g., *15*) that may have higher-frequency components, which would not affect overall driver-vehicle tracking performance (i.e., lane position and speed control). Curvature, heading, and lane position error measures relate to steering performance, whereas speed measures relate to speed control. Side task measures relate to monitoring performance and response to discrete events. Performance measurement intervals can be specified and data collected over multiple measurement intervals (e.g., every 2 min for 20 min).

Automated orientation and training features were added to the simulation to make experimental procedures and data collection more efficient. Questionnaires can be administered by the simulation computer on the display monitor. Subjects respond using a keypad that avoids the potential intimidation of a computer keyboard. A voice reproduction expansion card is incorporated to allow the simulation computer to administer training. Voice messages are recorded on the hard disk as files. These files can then be recalled by the simulator orientation and training program to present verbal instructions and interactive remedial training.

APPLICATION

As part of a study on the assessment of truck driver fatigue, baseline tests were run on a group of long-haul drivers using the part task driving simulator (Figure 5). Driving tasks presented to the driver were to control speed at a steady 55 mph and to maintain proper lane position. Drivers were required to drive on a straight road for 20 min with no events occurring other than the appearance of arrow and horn symbols in the side mirror subsidiary task. Because the objective of this test was to measure fatigue, the driving task was purposely designed to be monotonous. Instabilities in the steering and speed control tasks were set at low levels, 0.15 and 0.016 rad/sec, respectively. Subsidiary task symbols appeared on the average every 20 sec. The driving task lasted 20 min and performance on the steering, speed control, and subsidiary discrete response tasks was averaged over 2-min intervals.

Simulator performance was compared between two groups of 32 drivers each. One group was reporting for their driving

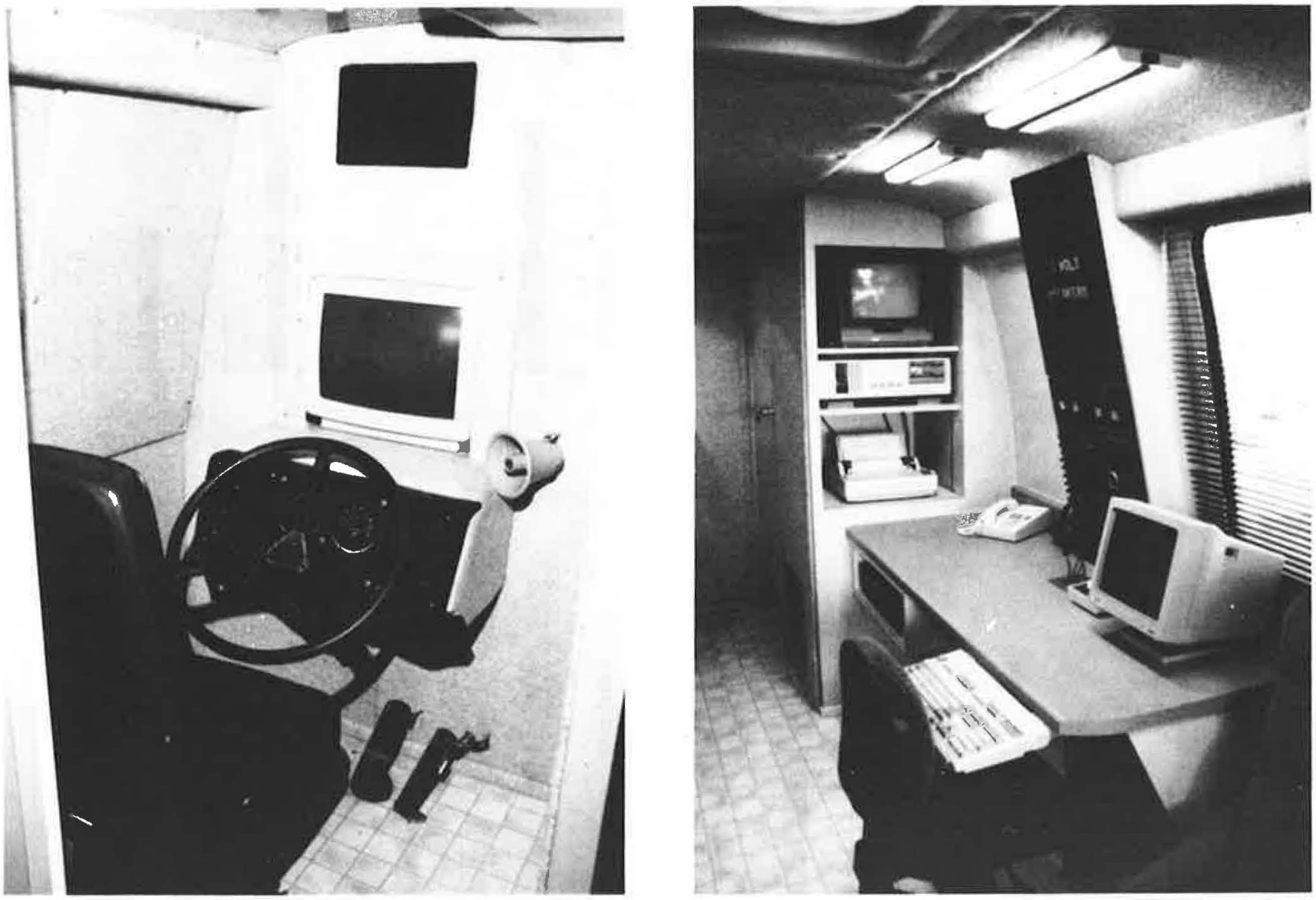

FIGURE 5 Part Task Simulation Setup: cab (*left*) and computer area (*right*).

shift, whereas the other group had returned from an 8- to 10-hr driving shift. Each driver was given a short orientation to the project and administered a pretest questionnaire by the simulation computer. The computer then automatically administered training on the task, including practice with each of the controls. Voice reproduction from the simulation computer first summarized the use of the turn indicators and horn in the side mirror task, then required their operation in response to the arrow and horn symbols. If controls were used incorrectly, the computer would correct the subject with a voice message and continue training. Training with steering only and speed control only was administered followed by combined control of steering, speed, and the subsidiary task. On successfully completing training, each subject was administered the 20-min data collection run.

Results of this application were successful. All subjects were successfully trained automatically by the simulation computer, and no simulator sickness was reported during or after the 20-min performance measurement drive. Significant differences in group performance were found for measures of steering control, speed control, and the subsidiary task discrete response. These performance results are shown in Figure 6. Typically, the performance of the before driving shift group stabilized after the first 2-min performance measurement period, whereas the after driving shift group never stabilized throughout the 20-min driving test. A between-group analysis of variance comparison of these effects showed the effects to be highly significant ($p < 0.005$).

CONCLUSION

Low-cost microcomputer technology can be effectively applied to the implementation of part task driving simulation. Although this simulator does not have the capability for full-fidelity simulation, there are a range of applications that make this low-cost approach attractive. Microcomputer technology can easily accommodate vehicle math models, roadway visual displays, and sound effects. Automated orientation and training features can also be implemented with voice reproduction capability as a means of increasing operational efficiency. This approach is suitable for research in diverse fields, such as the fatigue study discussed, and studies of other driving impairments (e.g., alcohol and drugs), and could be extended to study driver decision making and work load.

Microcomputer technology can also be extended to accommodate additional simulation features. The vehicle math model can be expanded to cover limit performance conditions in which tire force saturation leads to loss of control. Roadway scene display scenarios can be expanded to cover gap acceptance situations involved in turning and merging. Given more complete driving scenarios, this simulation approach might

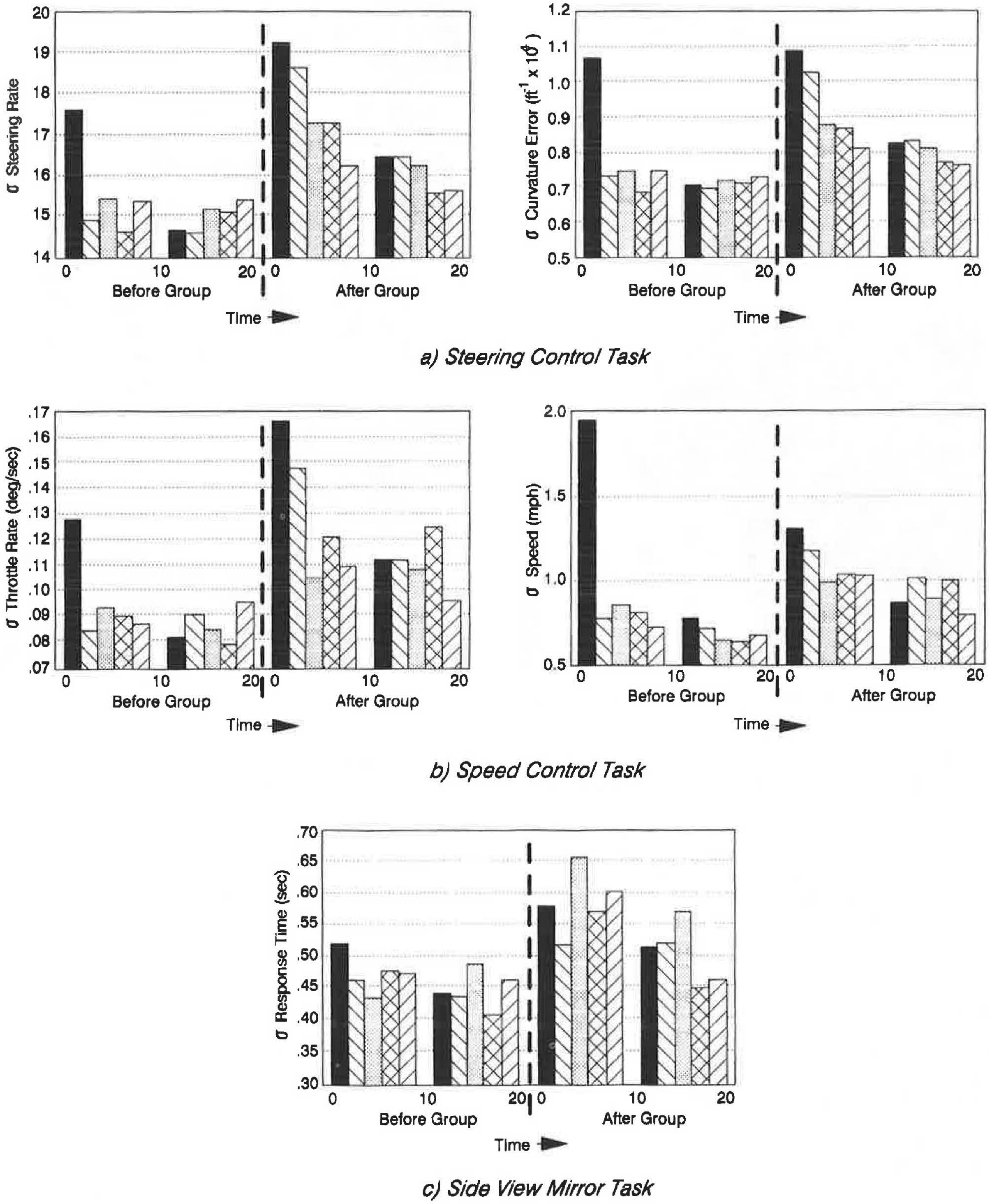

FIGURE 6 Test results summary.

have some limited use in driver training. With the rapidly expanding capability of microcomputer technology, it is expected that low-cost, PC-based part task simulation will become viable for an increasing range of applications in the near future, and may eventually be able to assist in driver training and licensing.

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