INFERENCES ABOUT EMERGENCY VEHICLE WARNING LIGHTING SYSTEMS FROM CRASH DATA

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Executive Summary

Firefighters who are killed in road traffic crashes are a substantial fraction of all firefighters who die in the line of duty. Consequently, understanding and addressing the circumstances that lead to these crashes are major concerns for firefighter safety. By their nature, the activities involved in firefighting involve substantial risks, and activities involving traffic are not exempt from such risks. Warning lamps are used on emergency vehicles in order to reduce traffic risks by increasing the conspicuity of those vehicles, and they are probably very effective in doing that. However, there has been concern that, if they are too strong, warning lamps could also increase the risk of certain types of crashes. Thus far, empirical evidence on this issue from crash data has been limited. The purpose of this report is to examine several sources of information about emergency-vehicle crashes and to use that information to make tentative recommendations about how warning lamps could be modified to increase safety.

The effectiveness of warning lamps as alerting devices is probably determined by several variables: light intensity, flash rate, abruptness of flash onset and offset, color, number of lamps, and configuration of lamps. The ways in which each of these variables may be related to positive or negative effects on emergency vehicle safety are complex. However, it may be possible to characterize warning lamps to a large extent on a single dimension, which might be referred to as their overall *strength*. Stronger lamps may be more effective in getting drivers to notice emergency vehicles, and thereby avoid many potential crashes. However, there may also be some negative effects of warning lamps—including visual effects such as glare and masking; and cognitive effects such as distraction, confusion, and disorientation. If greater strength also increases negative effects of warning lamps, then optimizing the design of warning lamps may involve determining the strength of lamps that yields the best tradeoff between conspicuity and those negative effects.

The following three sources of data for emergency vehicle crashes were examined: (1) state databases, covering fatal and nonfatal crashes, from Missouri and Florida, (2) the U.S. Fatality Analysis Reporting System (FARS), which covers all fatal crashes, and (3) a specialized database for all fatal firefighter traffic crashes. The more general-purpose databases can be used to identify emergency vehicle crashes in which the emergency vehicle was a contact vehicle; the specialized database was used primarily to identify crashes in which a firefighter was killed as a pedestrian, but in which no emergency vehicle was a contact vehicle.

The crash data examined here provide several findings with possible implications for the effectiveness of warning lamps. The state databases yielded the most directly applicable findings. Emergency vehicles are involved in fewer angle crashes in the dark, consistent with the hypothesis that warning lamps are effective in preventing those crashes because the lamps are

more salient in darker ambient conditions. In addition, changes in the warning lamps on fire trucks with the 1998 model year may have improved their safety effectiveness, as suggested by reductions in the number of crashes on emergency runs relative to those not on emergency runs. Examination of police accident reports (PARs) for crashes involving firefighting vehicles in Florida suggested that there may be a substantial number of multiple-vehicle crashes (about 30% of the cases examined) in which drivers of the nonemergency vehicles did not detect the emergency vehicle. Stronger warning lamps might be able to address that problem. Information from the specialized database for fatal firefighter road traffic crashes indicated that firefighter pedestrian deaths are a substantial fraction of all incidents in which firefighters are killed in road traffic (25 of 98 incidents). There were suggestions that warning lamps may have sometimes reduced the likelihood of drivers detecting and avoiding the pedestrian, but the likelihood of detection in those cases may have been low even without any negative effects of warning lamps.

Although these results contribute to knowledge about how warning lamps may affect the risk of emergency vehicle crashes, that knowledge is still quite limited and suggestions for improvements in warning lamps must be considered tentative. For purposes of discussion and further investigation, more than for immediate action, we offer the following suggestions: (1) Given the considerations if the previous paragraph, stronger warning lamps might reduce the risk of crashes in which another driver fails to detect an emergency vehicle. There does not appear to be strong evidence that stronger lamps would result in significant negative effects. (2) Given the possibility that there is a tradeoff between the conspicuity of warning lamps and negative effects of those lamps, options for warning lamps that may change that tradeoff seem worth considering.

The results of this project lead to several possible approaches for further research to better understand how warning lamps affect emergency vehicle safety. First, in order to overcome the limits of existing crash databases, it may be valuable to directly observe the behavior of other vehicles around an emergency vehicle engaged in emergency operation, either while in transit or while parked at an emergency site. Second, the possibility that warning lamps at night reduce the visibility of emergency personnel as pedestrians should be directly studied with human-performance field work.

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1 Introduction

1.1 Overview of project goals and methods

Firefighters who are killed in road traffic crashes are a substantial fraction of all firefighters who die in the line of duty. Among all causes of firefighter fatalities, traffic crashes are second only to stress/overexertion. Consequently, understanding and addressing the circumstances that lead to road traffic crashes are major concerns for firefighter safety. By their nature, the activities involved in firefighting involve substantial risks, and activities involving traffic are not exempt from such risks. Warning lamps are used on emergency vehicles in order to reduce traffic risks by increasing the conspicuity of those vehicles, and they are probably very effective in doing that. However, there has been concern that, if they are too strong, warning lamps could also increase the risk of certain types of crashes (e.g., Solomon, 2002). Thus far, empirical evidence on this issue from crash data has been limited. The purpose of this report is to examine several sources of information about emergency-vehicle crashes and to use that information to make tentative recommendations about how warning lamps could be modified to increase safety.

The effectiveness of warning lamps as alerting devices is probably determined by several variables: light intensity, flash rate, abruptness of flash onset and offset, color, number of lamps, and configuration of lamps. The ways in which each of these variables may be related to positive or negative effects on emergency vehicle safety are complex. However, it may be possible to characterize warning lamps to a large extent on a single dimension, which might be referred to as their overall *strength*. Stronger lamps may be more effective in getting drivers to notice emergency vehicles, and thereby avoid many potential crashes. However, there may also be some negative effects of warning lamps—including visual effects such as glare and masking; and cognitive effects such as distraction, confusion, and disorientation. If greater strength also increases negative effects of warning lamps, then optimizing the design of warning lamps may involve determining the strength of lamps that yields the best tradeoff between conspicuity and those negative effects.

The effects of warning lamps, either positive or negative, might influence the risks of various types of crashes. These crashes include those in which an emergency vehicle is involved as a contact vehicle, but they also include pedestrian crashes in which someone is struck near an emergency vehicle. There has been concern that, because of distraction or glare, warning lamps may increase the risk of such crashes. Crashes in which a firefighter is hit and killed as a pedestrian are a substantial minority of all cases in which firefighters are killed in transportation incidents. Clarke and Zak (1999) reported that, over the 6-year period from 1992 to 1997, 90 firefighters were killed in transportation incidents, of which 16 (about 18%) were pedestrians. Over the same period, 259 firefighters in all were killed by injuries in the line of duty, meaning that the pedestrian deaths were about 6% of all injury deaths in the line of duty. The corresponding values for deaths of law enforcement personnel over the same period were similar in proportions, although several times higher overall: there were 887 total fatal injuries, of which 384 were in transportation incidents, of which, in turn, 66 were pedestrians. Thus, fatalities for law enforcement personnel as pedestrians were about 17% of all transportation fatalities and 7% of all injury fatalities.

In the analyses reported here, we used several variables to categorize crashes in order to make inferences about the effects of warning lamps included. The major variables were: whether or not the emergency vehicle was on an emergency run, whether the crash occurred during the day or at night, whether the crash involved a single or multiple vehicles, and whether the model year for the emergency vehicle was prior to 1998, a year in which major changes were made in the standards for warning lamps on fire trucks.

The following three sources of data for emergency vehicle crashes were examined: (1) state databases, covering fatal and nonfatal crashes, from Missouri and Florida, (2) the U.S. Fatality Analysis Reporting System (FARS), which is maintained by the National Highway Traffic Safety Administration (NHTSA) and covers all fatal crashes in the U.S., and (3) a specialized database for all fatal firefighter traffic crashes (Roche, 2004). The more general-purpose databases can be used to identify emergency vehicle crashes in which the emergency vehicle was a contact vehicle; the specialized database was used primarily to identify crashes in which a firefighter was killed as a pedestrian, but in which no emergency vehicle was a contact vehicle.

1.2 Previous research

Several comprehensive studies of vehicle warning lamps have been documented, and there is a reasonable level of consensus among them on many issues. The greatest agreement is arguably with regard to the need to standardize warning signals. A study by Post (1978) was motivated by concern at the National Highway Traffic Safety Administration (NHTSA) that the multiplicity of warning signals that prevailed within the U.S. at that time (and which still exists) might confuse motorists unnecessarily. Post made comprehensive, although tentative, recommendations for a standard set of signals. His recommendations were tentative primarily because of the lack of information about the relationships between warning lamps and crash data.

Howett, Kelly, and Pierce (1978) and Rubin and Howett (1981) also strongly emphasized the need to standardize warning signals. Rubin and Howett, for example, pointed out that—

although only police, fire, and ambulance vehicles are generally regarded as true emergency vehicles—there were 25 categories of vehicles authorized to display warning lamps in various states and localities. They also documented the extreme variety of practice with respect to lamp color in the U.S., just within police vehicles. Four different colors (red, blue, yellow, and white) were all in reasonably common use, either alone or in various combinations.

In spite of strong and nearly universal urging from researchers to standardize signals, it is not clear that this will be accomplished soon. One reason for this may be that the arguments have been based primarily on principles of human factors and vision rather than on empirical safety data. A central goal of the present project is to help remedy that situation by expanding the range of crash data that can be used to make inferences about the performance of warning lamps.

Although there has been a substantial amount of research on warning lamps, it has been considerably less than the work that has been done on the more standard forms of vehicle lighting—signaling and marking lamps, and headlamps (for reviews see Henderson, Sivak, Olson, & Elliott, 1983; Perel, Olson, Sivak, & Medlin, 1983; Sivak & Flannagan, 1993). Although the requirements of warning lamps are highly specialized, and relatively severe, it may be possible to make some inferences about the effectiveness of warning lamps from the large body of work on more general purpose vehicle lighting. This may be particularly true for issues concerning glare and visibility, which should be common to both domains. For example, a substantial body of work exists on the extent to which the glare of oncoming headlamps reduces the ability of drivers to see pedestrians (e.g., Bhise, Farber, Saunby, Troell, Walunas, & Bernstein, 1977; Flannagan, Sivak, Traube, & Kojima, 2000; Perel, Olson, Sivak, & Medlin, 1983).

2 Fatal and Nonfatal Databases From Selected States

In this section, we describe a series of analyses of state crash databases that cover fatal and nonfatal crashes. We used databases from Florida and Missouri because these states code whether any of the vehicles involved in a crash are emergency vehicles, and whether the emergency vehicles were on emergency runs. We began using the Missouri database, and later added the Florida database as a supplement. As a result, the most extensive analyses have been performed with the Missouri data, although in principle similar analyses could be extended to Florida, and perhaps other states.

We first report analyses performed with three years (1999-2001) of the Missouri data, then we report more detailed analyses that we performed after building a larger, five-year Missouri file (1999-2003). The later analyses partly overlap with the earlier ones, but the earlier analyses were not all repeated. We then report analyses of the Florida cases, which are based on coding of additional information from police accident reports (PARs) that we used to supplement the existing state database.

Where appropriate, statistical tests were performed to determine whether apparent differences had a substantial likelihood of resulting from chance alone. Where a test showed that there was less than a one-in-twenty chance (i.e., a probability of 0.05) that the observed difference would have resulted from chance alone, we call such differences "statistically significant." Statistical significance is not a measure of practical significance. It is just an indication of the probability that an apparent effect might be due to chance alone, rather than being a real, repeatable aspect of the data.

2.1 General method

We believe that crash risk is associated with a variety of conditions (dark/light, emergency vehicle type, model year for fire trucks) and operations (emergency vehicle type, emergency run or not). But we have no exposure information to measure the risks directly and to parcel it out among the factors named.

Because we do not have the tools to measure risk directly, we have to resort to indirect means. Primarily, this means measuring the differences in the proportion of involvements where we would expect the risk to be higher. This is greatly complicated by the fact that the primary factor of interest—emergency warnings—is inseparable from a known risk-increasing factor, i.e., the more aggressive driving style employed at the same time as the warnings. In other words, what we can identify in the crash data—whether on an emergency run—is in fact a compound of two influences that pull in opposite directions.

The characteristics of overall operations among the three emergency vehicle types differ. Police vehicles patrol regularly, and part of their charge is to interact with the traffic stream to enforce traffic laws. Thus, nonemergency runs are more likely to account for a larger share of their operations, and, furthermore, those nonemergency runs may be more uniformly distributed with respect to time, relative those of the other emergency vehicle types. Note this is "more uniformly" in comparison to the other emergency vehicle types, not uniformly. Fire trucks and ambulances respond to specific emergencies; they do not regularly patrol for fires or heart attacks. Their nonemergency runs thus are either returning from an emergency, which can happen at any time, or routine maintenance/housekeeping type of operations (grocery runs etc.) that presumably would primarily occur during the day.

Characteristics of emergency runs for all three emergency vehicle types, however, have a lot in common. Emergency runs, in contrast to "normal" operations, may involve higher speed driving, operating outside of normal traffic laws such as passing through red lights or stop signs without stopping, and the use of visual (warning lamps) and auditory (sirens) warnings. Both the higher speed driving and exceptions to ordinary traffic laws raise the likelihood of conflicts with other road users. The warnings are intended to address the increased risk by notifying the other road users of the emergency vehicle. The warnings include both sound and light; it can be expected that the visual warnings (lamps) will be more effective in the dark, because other sources of visual stimulation are then reduced, leaving the lamps more effective in contrast. The effectiveness of sirens, on the other hand, should be unaffected by light condition.

In summary, driving style during an emergency run tends to increase risk, while the warnings tend to decrease risk, and the two warning types would be expected to interact differently with light condition. The problem is to differentiate the effects of aggressive driving and warnings. One possibility is to estimate the different apparent effectiveness of sound and light in delivering a warning by light condition.

2.2 Initial summary of Missouri data (1999-2001)

An analysis file was constructed combining three years of data on crashes reported in Missouri. The original files from which the analysis file was drawn contain all police-reported crashes occurring in Missouri from 1999 to 2001. Missouri was selected because it covers all crash severities and distinguishes type of emergency vehicle (police, fire, ambulance, and other) and whether the vehicle was on an emergency run.

The tables shown in this section cover the three years of data. Note that the frequencies shown are not *annual* frequencies but the total for the three years. The bottom half of each table shows percentage distributions. Missouri provides a substantial number of cases to support analysis, with 5,594 emergency vehicles in crashes, including 556 crash-involved fire trucks available for analysis.

Table 1 shows the distribution of all emergency vehicles involved in crashes in Missouri, 1999-2001, by crash severity. Crash severity is a measure of the most severe injury in the crash, which may or may not be in the emergency vehicle. Severity is measured by the KABCO scale, in which K corresponds to a fatal injury, A is an incapacitating injury, B is a non-incapacitating but evident injury, and C injury is a complaint of pain. Of the 5,594 emergency vehicles in a crash, 81.3% were police vehicles, 9.9% were fire vehicles, 8.1% were ambulances, and 0.6% were some other type of emergency vehicle. There were 16 fatal involvements (0.3%), including 11 involving a police car and five involving a fire vehicle. Interestingly, the distribution of crash severity for emergency vehicles is somewhat less severe than for all vehicles. Among all vehicles involved in a crash in Missouri, 3.9% involve a fatality or A-injury, compared with 2.7% for emergency vehicles.

Table 1 Emergency vehicles in crashes by crash severity
Missouri police-reported data, 1999-2001

Most severe injury in crash	Police	Fire	Ambulance	Other emergency vehicle	Total
Fatal	11	5	0	0	16
A injury	103	17	10	4	134
B injury	400	41	43	3	487
C injury	458	42	36	1	537
Property damage only	3,578	451	366	25	4,420
Total	4,550	556	455	33	5,594
	Column percentages				
Fatal	0.2	0.9	0.0	0.0	0.3
A injury	2.3	3.1	2.2	12.1	2.4
B injury	8.8	7.4	9.5	9.1	8.7
C injury	10.1	7.6	7.9	3.0	9.6
Property damage only	78.6	81.1	80.4	75.8	79.0
Total	100.0	100.0	100.0	100.0	100.0

Missouri codes whether the vehicle was on an emergency run at the time of the crash, which is why Missouri data were selected for analysis. Our preliminary assumption is that vehicles on emergency runs have their warning light system activated. As shown in Table 2, over 20% of the vehicles were on an emergency run at the time of the crash. Over one-third (191) of the fire trucks were on a run.

Table 2 Emergency vehicle type by run type
Missouri 1999-2001

Vehicle type	On emergency run? Yes	No	Total
Police	771	3,779	4,550
Fire	191	365	556
Ambulance	136	319	455
Other emergency vehicle	33	0	33
Total	1,131	4,463	5,594
	Row percentages		
Police	16.9	83.1	100.0
Fire	34.4	65.6	100.0
Ambulance	29.9	70.1	100.0
Other emergency vehicle	100.0	0.0	100.0
Total	20.2	79.8	100.0

Table 3 shows light condition at the time of the crash for different emergency vehicle types involved in a crash. Note that all emergency vehicles are included, not just those on an emergency run. Overall, 56.7% of the involvements occurred in daylight. This percentage is substantially lower than the involvements for all vehicles (emergency and nonemergency): in 2001, 71.6% of all crashes in Missouri occurred in daylight. However, the distribution of light condition varies among the three types of emergency vehicles. In comparison to police and ambulance vehicles, the distribution of light condition for fire trucks is more like that of all vehicles, with 70.0% in daylight, 16.5% after dark with street lights on, and 12.1% after dark with no street lights.

Table 3 Light condition at the time of the crash, by emergency vehicle type
Missouri 1999-2001

Light condition	Police	Fire	Ambulance	Other emergency vehicle	Total
Daylight	2,453	389	304	27	3,173
Dark-street lights on	1,145	92	102	1	1,340
Dark-street lights off	46	6	4	0	56
Dark-no street lights	873	67	43	5	988
Unknown	33	2	2	0	37
Total	4,550	556	455	33	5,594
	Column percentages				
Daylight	53.9	70.0	66.8	81.8	56.7
Dark-street lights on	25.2	16.5	22.4	3.0	24.0
Dark-street lights off	1.0	1.1	0.9	0.0	1.0
Dark-no street lights	19.2	12.1	9.5	15.2	17.7
Unknown	0.7	0.4	0.4	0.0	0.7
Total	100.0	100.0	100.0	100.0	100.0

Table 4 shows light condition by emergency run for emergency vehicles. Note that the distribution is similar, with a somewhat higher percentage (statistically significant) of crashes occurring in the dark with no street lights—21.2% of emergency runs compared with 16.8% of nonemergency runs.

Table 4 Light condition at the time of the crash, by run type
Missouri 1999-2001

	On emergency run?		
Light condition	Yes	No	Total
Daylight	626	2,547	3,173
Dark-street lights on	250	1,090	1,340
Dark-street lights off	10	46	56
Dark-no street lights	240	748	988
Unknown	5	32	37
Total	1,131	4,463	5,594
	Column percentages		
Daylight	55.3	57.1	56.7
Dark-street lights on	22.1	24.4	24.0
Dark-street lights off	0.9	1.0	1.0
Dark-no street lights	21.2	16.8	17.7
Unknown	0.4	0.7	0.7
Total	100.0	100.0	100.0

2.3 Crash types and incidence of injury in Missouri fire vehicle crashes

This section reviews findings from the 1999-2001 Missouri crash data about crash types, severities, and injuries to occupants of fire vehicles involved in crashes. Fire trucks are the most common type of vehicles involved, but it should be noted that about 30% of the vehicles are classified as pickups, SUVs, or passenger vehicles.

Table 5 shows the distributions of fire vehicle crashes by crash severity. Crash severity is measured by the most severe injury in the crash, not necessarily in the fire vehicle. Only about one-third (191/556 = 0.343) of fire vehicle crash involvements occurred while on an emergency run. Nevertheless, emergency runs tend to be more serious, at least in terms of the injury severity of the overall crash. In 14.1% of emergency run cases, the most severe injury in the crash was a fatal, A, or B injury, compared with 9.9% of crashes not while on an emergency run. This makes intuitive sense, since emergency runs would tend to be higher speed.

Table 5 Crash Severity by Emergency Run for Fire Vehicles

Crash severity	On emergency run?				Total	
	Yes		No			
	N	%	N	%	N	%
Fatal	3	1.6	2	0.5	5	0.9
A injury	11	5.8	6	1.6	17	3.1
B injury	13	6.8	28	7.7	41	7.4
C injury	19	9.9	23	6.3	42	7.6
No injury	145	75.9	306	83.8	451	81.1
Total	191	100.0	365	100.0	556	100.0

Table 6 shows the distribution of fire vehicle crash involvements by the number of vehicles involved in the crash. The number of vehicles involved is of interest here because single-vehicle crashes are unlikely to be affected by characteristics of the emergency light system. That is because the driver of an emergency vehicle is unlikely to be affected by the lights on his or her own vehicle, and that vehicle—by definition—must be the only one directly involved in a single-vehicle crash. Other vehicles could sometimes be involved indirectly, as noncontact vehicles, but their roles will at least be diminished. By distinguishing single- from multiple-vehicle involvements, we will be able to focus more narrowly on the crashes that may be influenced by the emergency light system. It is assumed that if a vehicle is coded as on an emergency run, its warning light system is activated. Note that crashes on emergency runs are more likely to be single-vehicle. Almost a quarter of emergency run crashes were single-vehicle, compared with 16.4% of nonemergency crashes. This difference barely misses the standard we have adopted for statistical significance ($p = .051$, just above the criterion .05 level). But most crashes involve more than one vehicle. Still, the proportion of single-vehicle crashes is about 50% greater if the crash is on an emergency run. These single-vehicle crashes are likely not affected by perceptions of the emergency lights. The overrepresentation of single-vehicle crashes while on an emergency run suggests that vehicle control may be an issue.

Table 6 Number of Vehicles Involved by Emergency Run for Fire Vehicles

Number of vehicles involved (including at least one fire vehicle)	On emergency run?				Total	
	Yes		No			
	N	%	N	%	N	%
One (fire vehicle only)	45	23.6	60	16.4	105	18.9
Two	136	71.2	287	78.6	423	76.1
Three	8	4.2	17	4.7	25	4.5
Four	0	0.0	1	0.3	1	0.2
Five	2	1.0	0	0.0	2	0.4
Total	191	100.0	365	100.0	556	100.0

Single-vehicle crashes that occur on an emergency run are more likely to be severe than nonemergency run single-vehicle crashes. Table 7 shows that 22.2% of emergency run crashes involve a fatality or an A or B injury, compared with only 13.3% of nonemergency run cases. In addition, 42.9% of single-vehicle crashes involving fire vehicles were while on an emergency run. Again, this likely speaks more to handling issues than other motorists' perceptions.

Table 7 Crash Severity in Single-Vehicle Crashes for Fire Vehicles

	On emergency run?					
	Yes		No		Total	
Crash severity	N	%	N	%	N	%
Fatal	2	4.4	1	1.7	3	2.9
A injury	4	8.9	0	0.0	4	3.8
B injury	4	8.9	7	11.7	11	10.5
C injury	4	8.9	4	6.7	8	7.6
No injury	31	68.9	48	80.0	79	75.2
Total	45	100.0	60	100.0	105	100.0

Multiple-vehicle crashes tend to be less severe than single-vehicle crashes, both overall and whether on an emergency run or not, as indicated by the severity distributions shown in Table 7 and Table 8 (e.g., overall, 75.2% of single-vehicle crashes have no injury, in comparison to 82.5% of multiple-vehicle crashes). Moreover, whether the vehicle was on an emergency run may make less of a difference in multiple-vehicle crashes. Fatal, A, and B injury crashes are only 11.6% of emergency run involvements, compared with 9.2% of the involvements on nonemergency runs. However, this difference is not large, nor is it statistically significant.

Table 8 Crash Severity in Multiple-Vehicle Crashes, Fire Vehicles

	On emergency run?					
	Yes		No		Total	
Crash severity	N	%	N	%	N	%
Fatal	1	0.7	1	0.3	2	0.4
A injury	7	4.8	6	2.0	13	2.9
B injury	9	6.2	21	6.9	30	6.7
C injury	15	10.3	19	6.2	34	7.5
No injury	114	78.1	258	84.6	372	82.5
Total	146	100.0	305	100.0	451	100.0

Table 9 shows the distribution of the first harmful event in single-vehicle crashes (i.e., only a fire vehicle was involved). Fixed-object crashes are collisions off the road. In cases where the first harmful event was a collision with an animal, there could have been a subsequent event, such as a roadway excursion followed by a collision with a fixed object. The distributions of crash type by whether the fire vehicle was on an emergency run are quite similar. Note the prevalence of rollover, however. Rollover substantially increases injury risk to vehicle occupants. The proportion of rollover seems high, but the instructions in the manual used by police clearly show that the code is used to indicate rollovers, and nothing else.

Table 9 Crash Type for Fire Vehicle Single-Vehicle Involvements

	On emergency run?				Total	
	Yes		No			
Collision with:	N	%	N	%	N	%
Animal	5	11.1	4	6.7	9	8.6
Bicyclist	0	0.0	1	1.7	1	1.0
Fixed object	27	60.0	38	63.3	65	61.9
Nonfixed object	1	2.2	2	3.3	3	2.9
Pedestrian	1	2.2	2	3.3	3	2.9
Rollover	8	17.8	11	18.3	19	18.1
Other	3	6.7	2	3.3	5	4.8
Total	45	100.0	60	100.0	105	100.0

In contrast to single-vehicle crashes in which only an emergency vehicle is involved, in multiple-vehicle crashes that include at least one emergency vehicle there will be at least some possibility that the warning lights of that vehicle were observed from, and thus may have had an influence on, another involved vehicle. Such collisions may therefore be expected to show more of an effect from the use of emergency lights. Table 10 shows the collision type in multiple-vehicle crashes. Collision type captures the relative position and motion of the vehicles. Note the prevalence of angle collisions while on emergency runs. Almost half of emergency involvements were angle collisions, in which the colliding vehicles are on intersecting paths, typically at an intersection. For fire vehicles not on emergency runs, only 27.2% of the crashes involved intersecting paths. Also note that in rear-end crashes, which one would expect to be affected by emergency lights, about the same proportion of striking and struck, when the crash occurred on an emergency run and thus the lights turned on. But when the fire vehicle was not on an emergency run, it is twice as likely to be struck in the rear as to be the striking vehicle. The other big difference is in the proportion of crashes in which the fire vehicle is backed into.

Table 10 Collision Type in Multiple-Vehicle Crashes by Emergency Run, Fire Vehicles

Collision type	On emergency run?				Total	
	Yes		No			
	N	%	N	%	N	%
Head-on	0	0.0	3	1.0	3	0.7
Rear-end striking	10	6.8	18	5.9	28	6.2
Rear-end struck	11	7.5	40	13.1	51	11.3
Sideswipe meeting	11	7.5	27	8.9	38	8.4
Sideswipe passing	34	23.3	67	22.0	101	22.4
Angle	69	47.3	83	27.2	152	33.7
Backed into	6	4.1	48	15.7	54	12.0
Other	4	2.7	13	4.3	17	3.8
Unknown	1	0.7	6	2.0	7	1.6
Total	146	100.0	305	100.0	451	100.0

Of the 556 fire vehicles involved in a crash, there were records for 507 occupants. Fully 70 of the fire vehicles did not have an occupant record, so these 507 occupants were recorded in 486 vehicles. Most (47 or 67.1%) of the 70 fire vehicles with no occupant records were parked at the time of the crash. An additional 21 were coded as stopped in traffic. These vehicles were likely unoccupied. The other two vehicles were coded as skidding and starting from a parked position, respectively, so it is certainly possible that the latter was also unoccupied. The former may be an error.

Table 11 shows the distribution of injuries by severity and location of the occupants of fire vehicles involved in crashes. There were three fatalities in a fire vehicle, including two drivers and one right-front passenger. There was only one injury to a rider in an "unenclosed area," presumably a firefighter in one of the external standing positions. Drivers accounted for 480 out of the 507 occupant records and 42 out of the 64 injured firefighters. There may be an undercount of the number of occupants on a fire vehicle. It is possible that uninjured fire vehicle occupants are missed.

Table 11 Fire Vehicle Occupant Injuries by Severity and Location

Injury severity	Driver	Front Right	Second row	Third Row	Unenclosed area	Unknown	Total
Fatal	2	1	0	0	0	0	3
A injury	9	1	3	0	0	0	13
B injury	16	5	1	0	0	0	22
C injury	15	4	5	1	1	0	26
None	430	0	0	0	0	0	430
Unknown	8	0	0	0	0	5	13
Total	480	11	9	1	1	5	507

Table 12 shows fire vehicle occupant injuries by whether the vehicle was on an emergency run. More injuries occur on emergency runs (34, compared with 30 on nonemergency runs), even though substantially more vehicles were involved in nonemergency run crashes. This is consistent with an earlier table (Table 5), which showed that emergency run crashes were likely to be more severe than nonemergency runs.

Table 12 Fire Vehicle Occupant Injuries by Severity and Emergency Run

Injury severity	On emergency run?				Total	
	Yes		No			
	N	%	N	%	N	%
Fatal	2	1.0	1	0.3	3	0.6
A injury	10	5.1	3	1.0	13	2.6
B injury	7	3.5	15	4.9	22	4.3
C injury	15	7.6	11	3.6	26	5.1
No injury	160	80.8	270	87.4	430	84.8
Unknown	4	2.0	9	2.9	13	2.6
Total	198	100.0	309	100.0	507	100.0

Single-vehicle crashes were earlier identified as more likely to include injuries. Emergency runs were also identified as more likely to include injuries. Table 13 shows the distribution of firefighter injuries in single-vehicle crashes by whether the vehicle was on an emergency run. Overall, 25.0% of the firefighters involved suffered at least some injury (K, A, B, or C), while 35.3% of those on emergency runs were injured and 16.4% of those not on an emergency run. This difference is statistically significant. However, since these are single-vehicle crashes, they are not likely to be affected by the emergency lighting system.

Table 13 Fire Vehicle Occupant Injuries by Severity and Emergency Run, Single-Vehicle Crashes

Occupant injury severity	On emergency run?				Total	
	Yes		No			
	N	%	N	%	N	%
Fatal	2	3.9	1	1.6	3	2.7
A injury	4	7.8	0	0.0	4	3.6
B injury	5	9.8	7	11.5	12	10.7
C injury	7	13.7	2	3.3	9	8.0
No injury	33	64.7	49	80.3	82	73.2
Unknown	0	0.0	2	3.3	2	1.8
Total	51	100.0	61	100.0	112	100.0

Table 14 shows the percentage of occupant injuries by crash type for fire vehicles involved in single-vehicle crashes. The percentages illustrate that the risk of injury in a single-vehicle crash depends strongly on what is struck. In the case of a vehicle as large as a fire truck (which is the predominant type of vehicle here), injury risk is related to hitting large, fixed objects or rolling over. The percentage of occupants injured in collisions with a fixed object was 18.5% and the percentage injured in rollovers was 35.2%. (The few occupants coded unknown on injury severity are excluded.)

Table 14 Percentage of Occupant Injury by Crash Type, Single-Vehicle Crashes

Crash type	Percentage of injury
Animal	0.0
Bicyclist	0.0
Fixed object	18.5
Nonfixed object	0.0
Pedestrian	0.0
Rollover	35.2
Other	16.7
Total	25.5

Table 15 shows that in multiple-vehicle crashes, the distribution of injuries does not differ greatly by whether the vehicle was on an emergency run. Overall, the probability of injury to a fire vehicle occupant is low relative to single-vehicle crash involvements, and the injuries are generally less severe. There were no firefighter fatalities in multiple-vehicle crashes. Moreover, the probability of injury to a fire vehicle occupant in a multiple-vehicle crash is about the same, whether the vehicle is on an emergency run or not.

Table 15 Fire Vehicle Occupant Injuries by Severity and Emergency Run, Multiple-Vehicle Crashes

Occupant injury severity	On emergency run?				Total	
	Yes		No			
	N	%	N	%	N	%
Fatal	0	0.0	0	0.0	0	0.0
A injury	6	4.1	3	1.2	9	2.3
B injury	2	1.4	8	3.2	10	2.5
C injury	8	5.4	9	3.6	17	4.3
No injury	127	86.4	221	89.1	348	88.1
Unknown	4	2.7	7	2.8	11	2.8
Total	147	100.0	248	100.0	395	100.0

Whether the fire vehicle was on an emergency run apparently does not affect the percentage of injury to fire vehicle occupants in multiple-vehicle crashes. However, there is a substantial effect on the distribution of types of collisions involved, with a higher proportion of angle collisions and lower proportion of rear-end struck collisions. Table 16 shows the percentage of occupant injury by crash type in multiple-vehicle crashes. In the table, all multiple-vehicle collisions are considered together, without regard to whether the fire vehicle was on an emergency run. Overall, the percentage of injury is low, with only 9.4% of involved fire fighters injured. While there are some differences, they are based on relatively few cases. The slightly higher probability of injury when the fire vehicle is struck, compared with striking, is somewhat surprising, but not statistically significant. Head-on collisions certainly have the greatest potential for injury, but there were only three head-on crashes in the data (see Table 10).

Table 16 Percentage of Occupant Injury by Crash Type,
Multiple-Vehicle Crashes

Crash type	Percentage of injury
Head-on	0.0
Rear-end striking	15.4
Rear-end struck	22.9
Sideswipe meeting	6.5
Sideswipe passing	0.0
Angle	13.2
Backed into	0.0
Other	0.0
Unknown	66.7
Total	9.4

Table 17 summarizes the results of the occupant injury analysis. The highest percentage of injuries to fire vehicle occupants is experienced in the single-vehicle crashes when the fire vehicle is on an emergency run. In contrast, multiple-vehicle crashes while on an emergency run have a relatively low percentage of occupant injury. The circumstances of being on a run clearly change the distribution of crash types in multiple-vehicle crashes. Angle collisions, in which the vehicles collide while on intersecting paths, are overrepresented on emergency runs, while the proportion of rear-end struck collision is reduced. But that trade-off does not greatly affect the percentage of occupant injury in multiple-vehicle collisions, which is low relative to single-vehicle collisions in either case.

Table 17 Probability of Occupant Injury by Emergency Run and Number of Vehicles in Crash

Number of vehicles in crash	Emergency run?		All
	Yes	No	
Single vehicle	35.3	16.9	25.5
Multiple vehicle	11.2	8.3	9.4

2.4 Supplementary analyses of Missouri data (1999-2003)

In this section, we describe a set of supplementary analyses that were performed after the initial reports and discussion of the analyses described in the previous section. For the new analyses, we built a larger, five-year file of Missouri data, covering the years 1999-2003. The file contains a total of 8,842 cases, but is dominated by 7,069 police cases. Only 919 cases involve fire vehicles, 791 involve ambulances, and 63 involve "other" emergency vehicles.

Table 18 shows the distribution of emergency vehicle type by whether it was on an emergency run. Overall, about one third of the crashes of fire vehicles occur on an emergency run, which is the highest proportion in the table. For ambulances, the proportion is 28.4% and for police it is only 18.1%. (The "other emergency vehicle" type only shows crashes while on an emergency run. It is believed these vehicles are private vehicles that can be operated as emergency—such as volunteer firemen. When not on an emergency, they revert to their normal status. Most are passenger vehicles, though about one-quarter of the 63 "other emergency vehicle" types are coded as a tractor trailer or tractor with multiple trailers. Nevertheless, it is probably fair to drop these vehicles on occasion.)

Table 18 Emergency Vehicle on Runs, by Emergency Vehicle Type, Missouri 1999-2003

Vehicle type	Emergency run		Total
	Yes	No	
Police	1,280	5,789	7,069
Fire	305	614	919
Ambulance	225	566	791
Other	63	0	63
Total	1,873	6,969	8,842
Police	18.1	81.9	100.0
Fire	33.2	66.8	100.0
Ambulance	28.4	71.6	100.0
Other	100.0	0.0	100.0
Total	21.2	78.8	100.0

A fundamental distinction in crashes, that would seem to be particularly relevant when considering the effects of emergency warning lamps, is between single-vehicle and multiple-vehicle crashes. In single-vehicle crashes, warning lamps should have little effect on how the crash occurred. Single-vehicle crashes have more to do with vehicle and driver performance and less to do with the responses of other roadway users. In contrast, emergency warning lamps are intended to modify the behavior of other road users, so some fraction of crashes in which the emergency lamps were on may be caused either by failing to modify that behavior or modifying it in an undesirable way.

Table 19 shows the distribution of run type across the number of motor vehicles involved in the crash for each of the three emergency vehicle types. Emergency crashes are more likely to involve one or more other vehicles than nonemergency crashes, for each emergency vehicle type. That is, a higher proportion of emergency crashes involve a collision with another vehicle, rather than a single-vehicle event. The distributions are similar for police and fire vehicles. Ambulances have higher proportions of two-vehicle crashes and lower proportions of single-vehicle crashes, but a similar relationship between emergency and nonemergency runs.

Table 19 Emergency Vehicle on Runs, by Emergency Vehicle Type, and Number of Vehicles, Missouri 1999-2003

Number of motor vehicles	Police		Fire		Ambulance	
	Emergency run		Emergency run		Emergency run	
	Yes	No	Yes	No	Yes	No
1	477	2,552	106	285	56	191
2	714	2,946	183	296	156	343
3 or more	89	291	16	33	13	32
Total	1,280	5,789	305	614	225	566
1	37.3	44.1	34.8	46.4	24.9	33.7
2	55.8	50.9	60.0	48.2	69.3	60.6
3 or more	7.0	5.0	5.2	5.4	5.8	5.7
Total	100.0	100.0	100.0	100.0	100.0	100.0

2.4.1 Single-vehicle crashes

Table 20 shows the "crash type" for single-vehicle crashes of emergency vehicles by whether the vehicle was on an emergency run. In this case, the crash type is the first harmful event in the crash—the first event in the crash that either caused injury or damaged property. The distribution of crash type is quite different for emergency and nonemergency runs. About one-third of nonemergency run crashes are collisions with a fixed object, which means that the vehicle had to first leave the roadway, typically due to loss of control. In addition, about 31% of these nonemergency runs involve a collision with a parked car, and 23.7% involve a collision with an animal. Collisions with fixed objects account for 59.9% of emergency-run, single-vehicle crashes and only 16.8% are collisions with a parked car.

Table 20 Crash Types by Emergency Run Status,
Single-Vehicle Crashes

Crash type	Emergency run		Total
	Yes	No	
Animal	75	718	793
Pedalcyclist	1	28	29
Fixed object	393	1,021	1,414
Other object	45	166	211
Pedestrian	7	46	53
Parked MV	110	940	1,050
Rollover	15	46	61
Other noncollision	10	60	70
Unknown	0	3	3
Total	656	3,028	3,684
Animal	11.4	23.7	21.5
Pedalcyclist	0.2	0.9	0.8
Fixed object	59.9	33.7	38.4
Other object	6.9	5.5	5.7
Pedestrian	1.1	1.5	1.4
Parked MV	16.8	31.0	28.5
Rollover	2.3	1.5	1.7
Other noncollision	1.5	2.0	1.9
Unknown	0.0	0.1	0.1
Total	100.0	100.0	100.0

Table 21 shows that single-vehicle, emergency-run crashes are somewhat more likely to occur in dark, unlighted conditions in comparison with nonemergency runs. Given the shorter sight distances in the dark, and the more aggressive driving style associated with an emergency run, this is to be expected.

Table 21 Light Condition by Emergency Run Status, Single-Vehicle Crashes

Light condition	Emergency run		
	Yes	No	Total
Day	255	1,268	1,523
Dark/lighted	120	686	806
Dark	275	1,028	1,303
Unknown	6	46	52
Total	656	3,028	3,684
Day	38.9	41.9	41.3
Dark/lighted	18.3	22.7	21.9
Dark	41.9	33.9	35.4
Unknown	0.9	1.5	1.4
Total	100.0	100.0	100.0

However, Table 21 is dominated by law enforcement vehicles, which make up 82% of the 3,684 emergency vehicles involved in single-vehicle crashes. When disaggregated by emergency vehicle type, some differences appear between the vehicles types (Table 22). Both police and fire vehicles show higher proportions of crashes in dark, unlighted conditions on emergency runs, in comparison with nonemergency runs. Over 47% of police emergency run crashes occur in the dark, compared with 37% of nonemergency runs. The proportions are lower for fire vehicles, but emergency run crashes in the dark are overrepresented compared with nonemergency runs. Ambulances on emergency runs show only a slight, and insignificant (statistically and otherwise) increase in the proportion of crashes in the dark.

Table 22 Light Condition by Emergency Run Status and Vehicle Type, Single-Vehicle Crashes

Light condition	Police		Fire		Ambulance	
	Emergency run		Emergency run		Emergency run	
	Yes	No	Yes	No	Yes	No
Day	159	979	55	189	33	100
Dark/lighted	90	590	20	52	9	44
Dark	225	944	29	40	14	44
Unknown	3	39	2	4	0	3
Total	477	2,552	106	285	56	191
Day	33.3	38.4	51.9	66.3	58.9	52.4
Dark/lighted	18.9	23.1	18.9	18.2	16.1	23.0
Dark	47.2	37.0	27.4	14.0	25.0	23.0
Unknown	0.6	1.5	1.9	1.4	0.0	1.6
Total	100.0	100.0	100.0	100.0	100.0	100.0

The differences among emergency vehicle types in how emergency status is associated with light condition could be accounted for by differences in operations. A primary function of police vehicles is to monitor traffic and engage in preventative patrolling. As a result, they are more likely to operate at night, in darkness, as part of their ordinary operations (i.e., not on emergency runs). In contrast, both fire vehicles and ambulances primarily respond to emergencies. They do not patrol, on the alert for either fires or people in need of transport, as the police do in performance of their protective functions. Emergencies can occur at any time, and thus fire and ambulances can be called out at any time. Some part of their nonemergency operations would be returning from emergencies, but a substantial part would be what might be called housekeeping operations, to maintain the vehicles or fire house operations. These activities are likely to be done primarily in the day. Thus, differences in exposure might account for the different distributions of crashes observed in Table 22.

2.4.2 Two-vehicle crashes

Two-vehicle crashes provide probably the cleanest crash subset in which to look for the effect of warning lamps. In two-vehicle crashes while on an emergency run, the other party either failed to perceive, comprehend, or respond to the warning lamps and siren. It is expected that warning lamps will be more effective in dark conditions. So, all other things being equal, if the distribution of runs was about equal between day and dark, we might expect a higher proportion of nonemergency run crashes to occur in dark conditions, when the emergency lamps in use on emergency runs would be more effective in warning other road users away. And similarly, we would expect a higher proportion of emergency run crashes to occur in daylight, because of the protective effect of the lamps during dark conditions and their lesser effectiveness in daylight.

But, of course, all other things are not equal. The lamp systems may have a protective effect in darkness, because they are more conspicuous at night than in the day, but darkness also increases the risk to the emergency vehicle driver because of shortened sight distances. While other road users may more easily see the emergency vehicle at night, the emergency lamps do not help the driver see other road users. There is no way, without exposure data, to gauge the interaction of these countervailing effects.

In the event, two-vehicle emergency run crashes are twice as likely to occur in dark/unlighted conditions compared with nonemergency runs (Table 23). Most of the difference is accounted for by law enforcement vehicles. Table 24 shows the distribution of light condition by emergency vehicle type separately for police, fire, and ambulance vehicles. Disaggregated this way, the difference for police vehicles is even greater than when all emergency vehicle types are considered together. But the differences are negligible for fire vehicles, and not statistically significant. Ambulances show a pattern similar to police vehicles, but the differences are small enough that they are not statistically significant, given the number of cases.

Table 23 Light Condition by Emergency Run Status, Two-Vehicle Crashes

Light condition	Emergency run		Total
	Yes	No	
Day	683	2,454	3,137
Dark/lighted	265	894	1,159
Dark	137	248	385
Unknown	9	34	43
Total	1,094	3,630	4,724
Day	62.4	67.6	66.4
Dark/lighted	24.2	24.6	24.5
Dark	12.5	6.8	8.1
Unknown	0.8	0.9	0.9
Total	100.0	100.0	100.0

Table 24 Light Condition by Emergency Run Status and Vehicle Type, Two-Vehicle Crashes

Light condition	Police		Fire		Ambulance	
	Emergency run		Emergency run		Emergency run	
	Yes	No	Yes	No	Yes	No
Day	411	1962	135	228	103	264
Dark/lighted	189	749	35	41	37	59
Dark	109	209	12	24	13	15
Unknown	5	26	1	3	3	5
Total	714	2946	183	296	156	343
Day	57.6	66.6	73.8	77.0	66.0	77.0
Dark/lighted	26.5	25.4	19.1	13.9	23.7	17.2
Dark	15.3	7.1	6.6	8.1	8.3	4.4
Unknown	0.7	0.9	0.5	1.0	1.9	1.5
Total	100.0	100.0	100.0	100.0	100.0	100.0

While it is not possible to disentangle the effect of darkness and from the effects of driving style and warning sound and lights in Table 24, there should be a detectable effect on crash configuration. Emergency runs are characterized by more aggressive driving, such as going through stop signs and red lights, even if cautiously, and sound and light to alert other drivers. The driving style should be more or less the same in the day and night, and the effect of sound should be more or less the same in the day or night, but one would expect the effect of light to be increased at night.

During the day, emergency lamps provide less contrast from the surrounding light level, so one would expect less effect from the lamps during the day. We would also suggest that the effect of the lamps is different based on the orientation of other vehicles with respect to the emergency vehicles. The lamps would be more noticeable from the front and to the rear, so that other road users who are either approaching the emergency vehicle head-on or going in the same direction would more readily notice the vehicle than vehicles approaching from the side, as at an intersection. So we would expect a higher proportion of angle collisions while on an emergency run, compared with nonemergency runs. But warning lamps should be more effective in dark conditions, so while one expects a higher proportion of angle collisions on emergency runs compared with nonemergency runs, the increase should be less in the dark than in the day.

Table 25 shows the distribution of crash configuration by light condition for emergency vehicles on emergency runs. Crash configuration gives a very simplified classification of crashes by the orientation of the vehicles. In head-on crashes, the vehicles are on the same road, going in opposite directions. The rear-end group covers cases in which the vehicles are on the same road and going in the same direction. It does not distinguish which vehicle was in the lead, so it does not distinguish cases where the other vehicle struck the emergency vehicle in the rear from cases where the emergency vehicle was striking.

Table 25 Crash Configuration by Light Condition for Emergency Runs

Crash configuration	Day	Dark/ lighted	Dark	Unknown	Total
Head-on	29	22	10	0	61
Rear-end	182	59	45	2	288
Angle	416	154	52	6	628
Other	43	22	23	1	89
Total	670	257	130	9	1,066
Head-on	4.3	8.6	7.7	0.0	5.7
Rear-end	27.2	23.0	34.6	22.2	27.0
Angle	62.1	59.9	40.0	66.7	58.9
Other	6.4	8.6	17.7	11.1	8.3
Total	100.0	100.0	100.0	100.0	100.0

Note the high proportion of angle collisions. Overall, 58.9% of emergency-run, two-vehicle crashes are angle collisions. Note also that the proportion of angle crashes in dark, unlighted conditions is substantially lower than in day or dark/lighted conditions. Both of these differences are statistically significant.

Table 26 shows the same distribution for nonemergency runs. The proportion of angle collisions is significantly lower for nonemergency runs, and correspondingly, the proportion of rear-end crashes is elevated. Head-on crashes account for very similar proportions between the two. The proportion of angle collisions is somewhat higher during the day than at night, but the differential is much less than for emergency runs.

Table 26 Crash Configuration by Light Condition for Nonemergency Runs

Crash configuration	Day	Dark/ lighted	Dark	Unknown	Total
Head-on	116	41	25	0	182
Rear-end	1,071	297	87	16	1,471
Angle	872	382	70	11	1,335
Other	364	116	52	5	537
Unknown	1	0	0	0	1
Total	2,424	836	234	32	3,526
Head-on	4.8	4.9	10.7	0.0	5.2
Rear-end	44.2	35.5	37.2	50.0	41.7
Angle	36.0	45.7	29.9	34.4	37.9
Other	15.0	13.9	22.2	15.6	15.2
Unknown	0.0	0.0	0.0	0.0	0.0
Total	100.0	100.0	100.0	100.0	100.0

2.4.3 Comparison across 1998 model year changes

Because of changes in standard NFPA 1901 of the National Fire Protection Association, fire vehicles from the 1998 model year on may be expected to have emergency light systems with better visibility from all angles around the vehicle. We have no direct evidence of how visibility actually changed, but the possibility that the standard changes had an effect makes it worthwhile to examine trends in crashes by model year. Assuming that the configuration and intensity of the emergency lighting systems did in fact improve, it would be expected that fire trucks with a model year of 1998 or later would have a lower proportion of crashes while on an emergency run.

A series of analyses were executed to examine this hypothesis. Crashes involving two or more vehicles were examined, since it is not expected that changes in the emergency warning lights would affect single-vehicle crashes. Taking all emergency vehicle types together, there was no significant difference in the proportion of emergency run crashes by emergency vehicle model year. Table 27 shows the distribution of run type (emergency or not) by model year of the emergency vehicle. There is no difference, practical or statistical, between the two distributions.

Table 27 Emergency Run Status, by Model Year

Emergency run	Pre-1998	1998 and later	Total
Yes	529	638	1,167
No	1,681	2,098	3,779
Total	2,210	2,736	4,946
Yes	23.9	23.3	23.6
No	76.1	76.7	76.4
Total	100.0	100.0	100.0

Table 28 shows the data in Table 27 disaggregated by emergency vehicle type. Forty-two "other" emergency vehicle types are excluded. Note that the comparison by model year category is different for each of the emergency vehicle types. For police vehicles, the later model years are actually more likely to be on an emergency run in a crash than the earlier model years. The difference only amounts to 3.8% but this difference is statistically significant, given the number of cases involved. Fire vehicles also show a difference in the model year categories distribution, but the difference is greater and the reverse of that observed for police vehicles. Almost 42% of multiple crashes involving pre-1998 fire vehicles occur while on an emergency run, compared with 31.8% of the later model years. Even though there are many fewer cases (502 compared with 3874 for police cars), this difference is statistically significant. And finally, there is no significant difference in the distribution of model year for ambulances.

Table 28 Emergency Run Status, by Vehicle Type and Model Year

	Police		Fire		Ambulance	
Emergency run	Pre-1998	1998 and later	Pre-1998	1998 and later	Pre-1998	1998 and later
Yes	276	491	137	55	89	77
No	1,298	1,809	192	118	191	171
Total	1,574	2,300	329	173	280	248
Yes	17.5	21.3	41.6	31.8	31.8	31.0
No	82.5	78.7	58.4	68.2	68.2	69.0
Total	100.0	100.0	100.0	100.0	100.0	100.0

The difference for fire vehicles is in the expected direction and is strong. Based on the likely effects of standard NFPA 1901, it appears that changes in emergency lights implemented in the 1998 model year may have had a strong positive effect. In contrast, no change was observed for ambulances, and the effect for police vehicles was small relative to fire vehicles and in the opposite direction. The provisional positive result for fire vehicles suggests that this line of analysis may be worth pursuing. Direct evidence about photometric differences for all three types of emergency vehicles from 1998 on would clarify the implications of this result.

Probably the purest test of the effect of the change in the emergency light standard is to look just at fire trucks in multiple-vehicle crashes. Table 29 shows the association between emergency run and model year for fire truck crashes. Almost 49% of the crash involvements of fire trucks with a model year before 1998 occurred while on an emergency run, while only 37.0% of later model fire truck crashes occurred on an emergency run. In percentage terms, this difference is greater than that observed for all fire vehicles (see the fire vehicle category in Table 28), but the finding just misses our standard for statistical significance ($p = .06$, rather than .05). Nevertheless, it is useful evidence showing a possible protective effect of the current emergency light system, in comparison with the previous system.

Table 29 Emergency Run Status by Model Year,
Fire Trucks

Emergency run	Model year		Total
	Pre-1998	1998 and later	
Yes	92	34	126
No	97	58	155
Total	189	92	281
Yes	48.7	37.0	44.8
No	51.3	63.0	55.2
Total	100.0	100.0	100.0

The Missouri police accident report allows the reporting officer to record up to five "driver contributing factors," which are, for the most part, driving errors that contributed to the crash. These are not charged violations. Charged violations are made at the discretion of the officer and reflect a judgment on whether a charge is appropriate, not just whether a violation occurred. In that sense, judgments about contributing factors may be somewhat more informative, because recording them does not commit the officer to any particular action. On the other hand, these contributing factors are determined after the fact, based on the officer's investigation and evaluation of available evidence.

Overall, the distribution of factors recorded match expectations. Table 30 shows the contributing factors for drivers of fire trucks in multiple-vehicle crashes. Note the restriction to fire trucks, not all fire vehicles. The drivers of fire trucks are somewhat more likely to have made a driving error while on an emergency run, but around 60% of the drivers were not recorded with an action that contributed to the crash. Of the driving factors, inattention was most frequently recorded, with 15.9% of the drivers noted on nonemergency runs and 19.5% recorded on emergency runs. Failure to yield, which seems unlikely while on an emergency run, was noted for 3.9% of drivers of fire trucks.

Table 30 Contributing Factors for Drivers of Fire Trucks, Multiple-Vehicle Crashes, by Run Type

Fire truck driver factors	Not on emergency run		Emergency run	
Driver contributing factor	N	%	N	%
None	98	62.4	75	58.6
Vehicle defects	8	5.1	5	3.9
Speed-too fast for conditions	3	1.9	4	3.1
Improper passing	0	0.0	1	0.8
Violation-stop sign or signal	1	0.6	1	0.8
Following too close	2	1.3	0	0.0
Improper backing	4	2.5	4	3.1
Improper turn	4	2.5	4	3.1
Improper lane usage/change	5	3.2	0	0.0
Improperly start from park	1	0.6	0	0.0
Improperly parked	2	1.3	0	0.0
Failure to yield	2	1.3	5	3.9
Inattention	25	15.9	25	19.5
Other	3	1.9	8	6.3
Driver violation unknown	3	1.9	3	2.3
Total fire truck drivers	157	100.0	128	100.0

Other vehicle drivers in crashes with fire trucks are significantly more likely to be recorded with a contributing factor than the drivers of the fire trucks, whether the fire truck was on an emergency run or not (Table 31). Only 44.0% of the other drivers were not recorded with a contributing factor when the fire truck was not on an emergency run, and only 38.1% were not recorded with a factor when the fire truck was on an emergency run. Inattention was recorded frequently, with about a quarter of drivers in both cases. However, failure to yield was recorded in 35.3% of the other drivers when the fire truck was on an emergency run, compared with 18.7% when it was not. This difference is statistically significant. It is also expected, since other road users are legally required to yield to emergency vehicles on a run. The difference in the proportion of failure to yield is the primary difference between the two distributions.

Table 31 Contributing Factors for Other Drivers in Collisions with Fire Trucks, Multiple-Vehicle Crashes by Run Type

Other driver factors	Not on emergency run		Emergency run	
Driver contributing factor	N	%	N	%
None	66	44.0	53	38.1
Vehicle defects	0	0.0	2	1.4
Speed-exceeding limit	3	2.0	0	0.0
Speed-too fast for conditions	11	7.3	9	6.5
Improper passing	5	3.3	1	0.7
Violation-stop sign or signal	6	4.0	1	0.7
Wrong side-no passing	2	1.3	1	0.7
Following too close	6	4.0	5	3.6
Improper backing	1	0.7	2	1.4
Improper turn	2	1.3	0	0.0
Improper lane usage/change	6	4.0	2	1.4
Improperly parked	2	1.3	3	2.2
Failure to yield	28	18.7	49	35.3
Drinking	3	2.0	0	0.0
Drugs	0	0.0	1	0.7
Physical impairment	2	1.3	0	0.0
Inattention	40	26.7	37	26.6
Other violation	10	6.7	6	4.3
Driver violation unknown	1	0.7	3	2.2
Total other drivers	150	100.0	139	100.0

Unfortunately, the driver contributing factors codes available do not illuminate the central focus of interest here, which is whether the emergency lights were perceived by other road users or, if they were perceived, did the lights disorient other road users. The list of coded driver factors does not address directly either question. Failure to yield can occur because the other road user did not see the lights, or was confused by the lights, or chose to ignore the lights, or misjudged the action of the emergency vehicle.

The Missouri PAR file includes a variable to record whether the driver's vision was obscured, and if so, by what. This variable was examined for the other vehicles in crashes with emergency vehicles. In 80-85% of the cases, the driver's vision was not coded as obscured. "Glare" was added as a category in 2002 and 2003, but it was recorded for only nine cases. Eight of those occurred in daylight and eight when the emergency vehicle was not on an emergency run.

2.5 Florida data

We had initially planned to supplement our analyses of the Missouri database with coding of details from the PARs for the cases that were of interest in 2001. However, although we were able to obtain PARs for 154 of the 333 cases from 2001, those were only the reports that were administered at the state level. Those cases are mostly if not entirely the cases that were originally investigated by the state police, and thus can be expected to be a strongly biased sample. As an alternative, we obtained PARs from Florida, which codes essentially the same information as Missouri in its database. Florida also has PARs with reasonably rich narratives and diagrams from which we could code the additional data of interest. Florida had 287 crashes involving firefighting vehicles in 2003. We obtained PARs for those cases.

We inspected the narratives and diagrams in the Florida PARs for indications that each case involved either a driver failing to recognize the presence of an emergency vehicle in emergency operation or, alternatively, a driver suffering negative effects of emergency lamps. Table 32 shows the classification of cases by the inferred role of emergency lamps and light condition. Overall, there was evidence in 29.6 percent of the cases that a driver had failed to see or respond properly to an emergency vehicle with emergency lamps on. Most of the cases in which the lamps are coded as irrelevant are nonemergency operation. It is a possible inference, although it goes beyond anything in the accident reports, that stronger warning lamps might have helped in those cases in which a driver apparently was not sufficiently alerted by the warning lamps. No cases in this set were coded as having indications of negative effects of the warning lamps. This result is broadly consistent with the findings of an independent survey of Missouri PARs (Menke, 2004).

Table 32 Police Accident Reports by Role of Lamps and Light Condition

Role of lamps	Day	Dark/ lighted	Dark	Dusk/dawn	Unknown	Total
Irrelevant	129	26	5	8	10	177
Possibly missed	61	10	5	9	0	85
Negative effect	0	0	0	0	0	0
Other/NA	18	5	0	1	0	24
Total	208	41	10	18	10	287
Irrelevant	62.0	63.4	50.0	44.4	100.0	61.7
Possibly missed	29.3	24.4	50.0	50.0	0.0	29.6
Negative effect	0.0	0.0	0.0	0.0	0.0	0.0
Other/NA	8.7	12.2	0.0	5.6	0.0	8.4
Total	100.0	100.0	100.0	100.0	100.0	100.0

Among the details that were coded from the accident reports were the orientations of the vehicles to each other in non-single-vehicle crashes. We coded the location of the primary nonemergency vehicle relative to the emergency vehicle in terms of the four sectors applied to warning lamps: A, B, C, and D for the forward, right, rear, and left quadrants, respectively. We coded the location of the emergency vehicle relative to the primary nonemergency vehicle in terms of clock directions—with 12 being straight ahead and 6 being directly behind. Figure 1 through Figure 4 show the case counts. Figure 1 and Figure 3 show all cases, while Figure 2 and Figure 4 show only those in which the role of emergency lamps was coded as not relevant or possibly missed. Figure 1 and Figure 2 show the location of the primary nonemergency vehicle relative to the emergency vehicle, and Figure 3 and Figure 4 show the location of the emergency vehicle relative to the primary nonemergency vehicle. The cases classified as "Other/NA" are primarily those with single vehicles.

For cases in which the emergency lamps were possibly missed, Figure 2 indicates a relative lack of representation when the primary nonemergency vehicle is behind the emergency vehicle (sector C). Figure 4 indicates a similarly low representation of those cases when the emergency vehicle is directly in front of or behind the primary nonemergency vehicle (positions 12 and 6, respectively). But Figure 4 indicates a relatively large representation of those cases when the emergency vehicle is in front of, but somewhat to the right or left of the nonemergency vehicle (positions 1, 2 and 10, 11). These patterns appear to reflect cases with right-angle intersection collisions. In those cases, the emergency vehicle is typically described as moving slower than the nonemergency vehicle, often having slowed to enter an intersection on a red light.

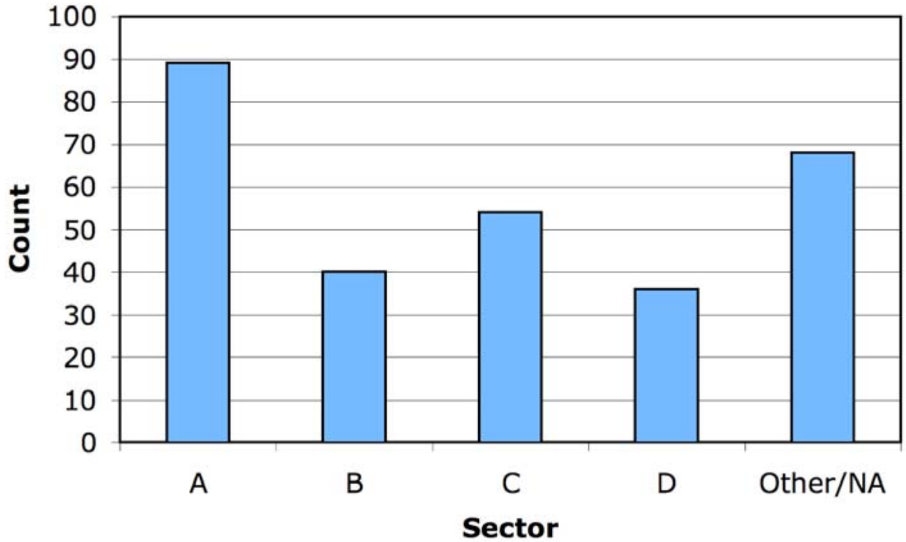

Figure 1. Counts of cases by location of the primary nonemergency vehicle relative to the emergency vehicle. Sectors: A (forward), B (right), C (rear), D (left).

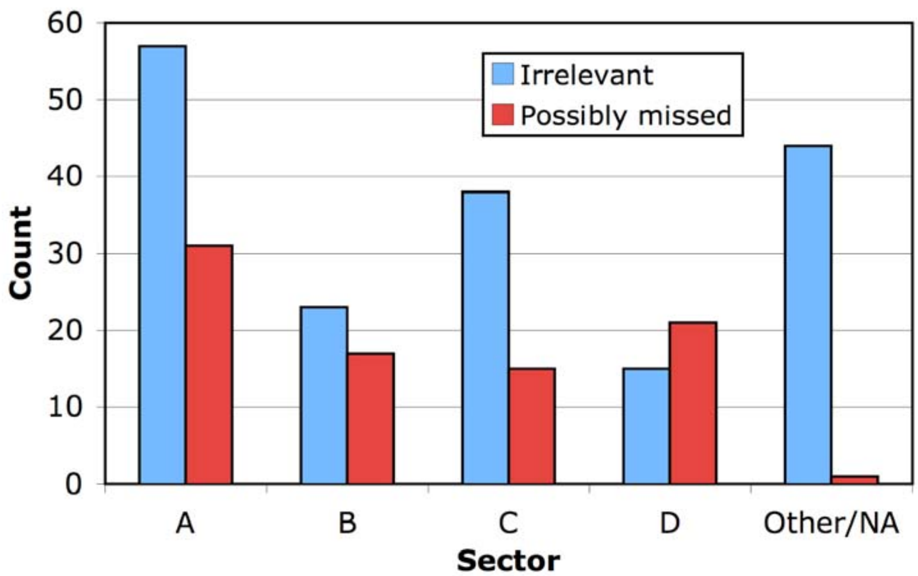

Figure 2. Counts of cases by location of the primary nonemergency vehicle relative to the emergency vehicle, for cases in which the emergency lamps were coded as irrelevant or possibly missed. Sectors: A (forward), B (right), C (rear), D (left).

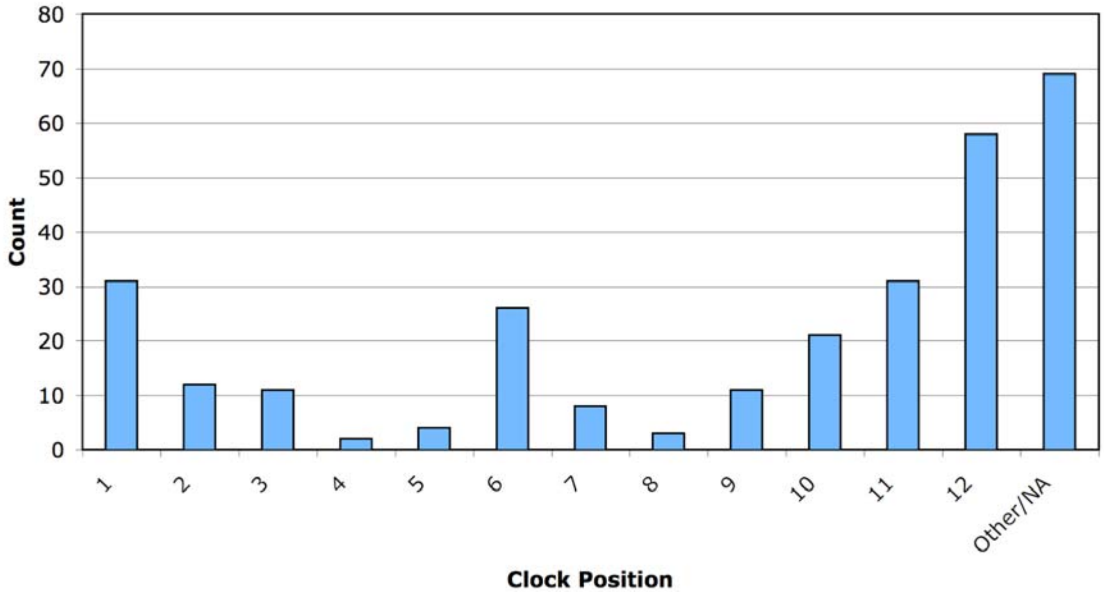

Figure 3. Counts of cases by location of the emergency vehicle relative to the primary nonemergency vehicle.

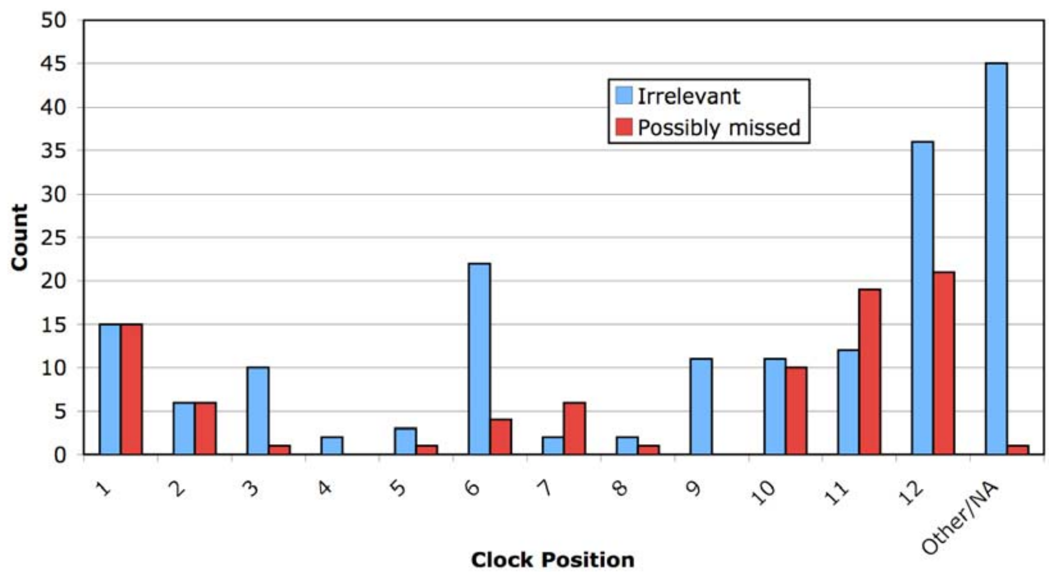

Figure 4. Counts of cases by location of the emergency vehicle relative to the primary nonemergency vehicle, for cases in which the emergency lamps were coded as irrelevant or possibly missed.

2.6 Discussion

The results described in this section illustrate several background aspects of emergency vehicle crashes that are important in themselves, but which are, for the most part, indirectly relevant to warning lamp performance. However, the results also provide a few findings that may be directly relevant to warning lamps.

Among the three types of emergency vehicles, police vehicles are involved in the greatest number of crashes. Fire vehicles and ambulances are reasonably close, and both well behind police vehicles in number of crashes. Most emergency vehicle crashes take place when the vehicle is not on an emergency run, although fire vehicles have the greatest proportion of crashes on emergency runs.

Categorizing emergency vehicle crashes by manner or collision and light condition yields the finding that there are substantially fewer angle collisions in dark conditions. Although the implications of this fact for warning lamps are indirect, it supports the hypothesis that warning lamps are more effective in the dark and thus they are able to prevent some number of angle collisions.

Because of changes in standard NFPA 1901, warning lamps on fire trucks with model years prior to 1998 can be expected to be different from those on fire trucks with model years from 1998 on. A comparison of the proportions of crashes that these vehicles are involved in while on emergency runs, versus not on emergency runs, suggests that the lamps used in 1998 and after may be more effective in preventing crashes. This is an inference based on the likely effects of changes in the standard. We do not currently have direct evidence about actual changes in the warning lamps with the 1998 model year, but the apparently positive result suggests that it may be worth pursuing this line of analysis.

The examination of narratives from accident reports for crashes involving firefighting vehicles in Florida suggested that there may be a substantial number of multiple-vehicle crashes in which drivers of the nonemergency vehicles did not detect the emergency vehicle; there were no cases with evidence for negative effects of warning lamps. Taken together, these two results suggest that stronger warning lamps might be beneficial because they are likely to be more conspicuous. However, the extent to which stronger lamps would actually be noticed more remains to be determined. It may be that when drivers fail to see current warning lamps they are so distracted or otherwise insensitive that even substantially stronger lamps would have limited benefits.

3 U.S. Fatal Crashes

This section describes analyses of emergency vehicle crashes in the Fatality Analysis Reporting System (FARS). This is a census of all fatal road traffic crashes in the U.S. Results in this section thus can be used to characterize the national extent and nature of safety problems involving emergency vehicles at the most severe level (fatal crashes). As with conventional state crash databases, this approach is limited in that it will not capture crashes in which an emergency vehicle might have been relevant if the emergency vehicle was not actually a contact vehicle in the crash. We first consider crashes involving fire, police, or ambulance vehicles, and then analyze the case of fire vehicles in more detail.

3.1 Data treatment

We constructed an analysis file from five years of FARS data, 1997-2001. For the file, we took all records of vehicles that were coded as either police, ambulance, or fire in the SPEC_USE (special use) variable. This variable provides the only means to identify emergency vehicles involved in fatal crashes.

Two files were constructed. The first was a vehicle file. The vehicle file includes all vehicles involved in a fatal crash with an emergency vehicle. A flag variable identifies the emergency vehicles. All FARS variables describing each vehicle are included, as are all the variables describing the crash and conditions at the time of the crash. An UMTRI-generated flag variable identifies the emergency vehicles in this file.

The second file includes all persons involved in the emergency vehicle crashes, including occupants of the emergency vehicles, occupants of other motor vehicles in the crash, and non-motorists involved, such as pedestrians or bicyclists. As in the case of the vehicle file, a flag variable identifies the occupants of the emergency vehicles.

The primary advantage of building files that include all participants is convenience. Some analytical questions relate to the other vehicles and persons in these crashes. For example, we might want to know about driver age and any impairment of the nonemergency drivers in the crashes. By preselecting the vehicles and occupants from the FARS file, we are able to quickly link the relevant data to the emergency vehicle records to evaluate any pattern present.

3.2 Results

Table 33 shows the distribution of cases available, by vehicle type and whether the vehicle was on an emergency run at the time of the crash. A total of 698 emergency vehicles were involved in a fatal crash from 1997 through 2001. Ninety-three of those vehicles were fire vehicles, 483 were police, and 122 were ambulances. Almost 47% (46.7%) were on an emergency run at the time of the crash. Fire vehicles were more likely to be operating under an emergency at the time of the crash than the other vehicle types. Almost 70% (68.8%) of fire vehicle fatal crashes were on an emergency run, compared with 56.6% of ambulances, and 40.0% of police vehicles.

Table 33 Emergency Vehicle Type by Emergency Run FARS 1997-2001

Emergency vehicle	On emergency run?		
	No	Yes	Total
Police	290	193	483
Ambulance	53	69	122
Fire	29	64	93
Total	372	326	698
	Row percentages		
Police	60.0	40.0	100.0
Ambulance	43.4	56.6	100.0
Fire	31.2	68.8	100.0
Total	53.3	46.7	100.0

Table 34 shows the distribution of body types of the various emergency vehicles. It is important to distinguish body type, because the different vehicle sizes and configurations will have different emergency lights and other warning (auditory) systems. As expected, most police vehicles involved in these crashes are light vehicles, typically passenger cars in configuration. Ambulances are largely small trucks, and most fire vehicles are trucks. The 81 fire trucks identified here are the main targets of the analysis. (See following section for details of those cases.)

Table 34 Body Type of Emergency Vehicles in Fatal Crashes
FARS 1997-2001

	Emergency vehicle type			
Body type	Police	Ambulance	Fire	Total
Light vehicle	444	7	4	455
Small truck	19	107	5	131
Truck	0	7	81	88
Small vehicle	17	0	0	17
Other	0	1	0	1
Unknown	3	0	3	6
Total	483	122	93	698
	Column percentages			
Light vehicle	91.9	5.7	4.3	65.2
Small truck	3.9	87.7	5.4	18.8
Truck	0.0	5.7	87.1	12.6
Small vehicle	3.5	0.0	0.0	2.4
Other	0.0	0.8	0.0	0.1
Unknown	0.6	0.0	3.2	0.9
Total	100.0	100.0	100.0	100.0

Table 35 shows the distribution of the first harmful event for each emergency vehicle type. First harmful event is defined as the first damage-causing or injury-producing event in a crash. The table covers all emergency vehicles involved in a fatal crash, whether on an emergency run or not. Note the higher percentage of rollovers as a first harmful event for fire vehicles, compared with the other types. Also note the high percentage (9.7%) of collisions with a fixed object. Both rollover and first event collision with a fixed object are characteristic of single-vehicle crashes, which tend to be associated with either the vehicle or its driver, rather than other motor vehicles.

Table 35 First Harmful Event by Emergency Vehicle Type
FARS 1997-2001

	Emergency vehicle type			
First harmful event	Police	Ambulance	Fire	Total
Rollover	14	2	15	31
Other noncollision	3	3	1	7
Ped./bike/animal	86	9	16	111
Motor vehicle	323	101	51	475
Fixed object	50	6	9	65
Nonfixed object	7	1	1	9
Total	483	122	93	698
	Column percentages			
Rollover	2.9	1.6	16.1	4.4
Other noncollision	0.6	2.5	1.1	1.0
Ped./bike/animal	17.8	7.4	17.2	15.9
Motor vehicle	66.9	82.8	54.8	68.1
Fixed object	10.4	4.9	9.7	9.3
Nonfixed object	1.4	0.8	1.1	1.3
Total	100.0	100.0	100.0	100.0

Table 36 shows the distribution of manner of collision with another motor vehicle for each emergency vehicle type. Manner of collision captures a simple collision configuration. Not applicable typically indicates single-vehicle crashes, though it also includes non-collision events. Note that fire vehicles have the highest proportion of not-applicable codes, with 45.2%, compared with 17.2% for ambulances and 33.1% for police cars. Rear-end collisions account for a negligible percentage (2.2%) of fire vehicle involvements. Angle collisions are the dominant collision configuration.

The distribution of fatal involvements by light condition is fairly similar for ambulance and fire vehicles (Table 37). Two-thirds of fatal involvements are in daylight for both ambulance and fire vehicles. In contrast, only 36.0% of police involvements are in daylight, 24.0% in dark conditions and 35.6% in dark/lighted (i.e., street lights) conditions.

Table 36 Manner of Collision by Emergency Vehicle Type
FARS 1997-2001

Manner of collision	Emergency vehicle type			
	Police	Ambulance	Fire	Total
Not applicable	160	21	42	223
Rear-end	46	9	2	57
Head-on	59	17	7	83
Rear to rear	1	0	0	1
Angle	207	73	39	319
Sideswipe, same	8	1	1	10
Sideswipe, opposite	2	1	2	5
Total	483	122	93	698
	Column percentages			
Not applicable	33.1	17.2	45.2	31.9
Rear-end	9.5	7.4	2.2	8.2
Head-on	12.2	13.9	7.5	11.9
Rear to rear	0.2	0.0	0.0	0.1
Angle	42.9	59.8	41.9	45.7
Sideswipe, same	1.7	0.8	1.1	1.4
Sideswipe, opposite	0.4	0.8	2.2	0.7
Total	100.0	100.0	100.0	100.0

Table 37 Light Condition by Emergency Vehicle Type
FARS 1997-2001

Light condition	Emergency vehicle type			
	Police	Ambulance	Fire	Total
Daylight	174	83	61	318
Dark	116	17	10	143
Dark/lighted	172	19	20	211
Dawn	8	2	1	11
Dusk	12	0	1	13
Unknown	1	1	0	2
Total	483	122	93	698
	Column percentages			
Daylight	36.0	68.0	65.6	45.6
Dark	24.0	13.9	10.8	20.5
Dark/lighted	35.6	15.6	21.5	30.2
Dawn	1.7	1.6	1.1	1.6
Dusk	2.5	0.0	1.1	1.9
Unknown	0.2	0.8	0.0	0.3
Total	100.0	100.0	100.0	100.0

Emergency fire vehicles are more likely to be involved in single-vehicle fatal crashes than either police or ambulances (Table 38.) Single-vehicle crashes accounted for 43.0% of fire vehicle fatal involvements, compared with 15.6% of ambulances and 26.7% of police fatal involvements. This is likely to be an indication of problems with handling and driving the vehicles, rather than collisions with other vehicles. Safety issues related to emergency lamps and auditory signals are more likely related to collisions with other motor vehicles. But note that collisions with other motor vehicles actually are a substantially lower proportion of fire fatal involvements than the other emergency vehicle types.

Table 38 Number of Vehicles in the Crash by Emergency Vehicle Type
FARS 1997-2001

Number of vehicles	Emergency vehicle type			
	Police	Ambulance	Fire	Total
One	129	19	40	188
Two or more	354	103	53	510
Total	483	122	93	698
	Column percentages			
One	26.7	15.6	43.0	26.9
Two or more	73.3	84.4	57.0	73.1
Total	100.0	100.0	100.0	100.0

3.3 Further analyses for fire trucks

The primary interest is in the fatal crashes of fire trucks, particularly on emergency runs. In this section, we focus on that group. In previous sections, we referred to fire "vehicles," which includes all body types, e.g., SUVs or sedans used by the higher ranks. Here, we include only fire vehicles classified as trucks.

The purpose of this section is to characterize the fatal crashes of fire trucks, particularly those on emergency runs, when, it is assumed, their emergency lamps are operating. The approach taken is to analyze crash conditions and crash configurations related to the use of emergency lamps. In the tables, crash involvements in which fire trucks were not on an emergency run are compared with the involvements of fire trucks on emergency runs. Tests of significance were calculated for each of the tables. None were found to be statistically significant, though sample sizes are quite small, even with five years of data. Many of the estimated differences are large enough to be of practical significance, however, and many of the associations discussed below are likely to be real, and could be checked with more years of data.

3.3.1 Single-vehicle involvements

Fire trucks on emergency runs are more likely to be involved in crashes with other vehicles than those not on emergency runs. Over half of the fatal involvements of fire trucks operating normally were single-vehicle (Table 39) compared with only 36.8% of involvements when on a run.

Table 39 Number of Vehicles in the Crash by Emergency Use
Fire Trucks Only
FARS 1997-2001

Number of vehicles	Emergency use		
	No	Yes	Total
Single	13	21	34
Two or more	11	36	47
Total	24	57	81
	Column percentages		
Single	54.2	36.8	42.0
Two or more	45.8	63.2	58.0
Total	100.0	100.0	100.0

This discussion first covers the single-vehicle involvements, and then multiple-vehicle involvements. Single-vehicle involvements by their nature do not involve interactions with other vehicles and so are worth treating separately.

First harmful event records the first injury-causing or damage-producing event in a crash sequence. It is of interest here as an indication of how the fire truck came to be involved in a crash. Though sample sizes are small, there are some interesting differences in the first harmful event by whether the fire truck was on an emergency run (Table 40). Three-quarters of the single-vehicle fatal involvements of fire trucks on emergency runs were either a rollover or a collision with a fixed object. Both events are an indication of a loss of control, leaving the roadway and either rolling over or colliding with a fixed object (or both). One-fifth of emergency run crashes involve a collision with a pedestrian, bicyclist, or other non-motorist. Fire trucks that were not on an emergency run have a lower percentage of the loss-of-control crash types, 53.9%, but a higher percentage of crashes with

Table 40 First Harmful Event by Emergency Use
Single-Vehicle Crashes, Fire Trucks Only
FARS 1997-2001

First harmful	Emergency use		
	No	Yes	Total
Rollover	6	8	14
Other noncollision	1	0	1
Ped./bike	5	4	9
Fixed object	1	7	8
Nonfixed object	0	1	1
Total	13	20	33
	Column percentages		
Rollover	46.2	40.0	42.4
Other noncollision	7.7	0.0	3.0
Ped./bike	38.5	20.0	27.3
Fixed object	7.7	35.0	24.2
Nonfixed object	0.0	5.0	3.0
Total	100.0	100.0	100.0

pedestrians or bicyclists. One interpretation of this difference is that the higher speeds associated with emergency runs result in loss-of-control, while normal operations are more associated with the hazards of maneuvering a large vehicle in urban areas.

Table 41 shows that single-vehicle crashes of fire trucks on emergency runs are somewhat more likely to occur in daylight than nonemergency runs. However, the differences are small (71.4% to 61.5%) and not statistically significant. We would not expect there to be much difference, because previous work has indicated that, with the exception of pedestrian crashes, single-vehicle crashes are not affected by the level of natural light (Sullivan & Flannagan, 2001).

Table 41 Light Condition by Emergency Use
Single-vehicle Crashes, Fire Trucks Only
FARS 1997-2001

	Emergency use		
Light condition	No	Yes	Total
Daylight	8	15	23
Dark	3	3	6
Dark/lighted	0	3	3
Dawn	1	0	1
Dusk	1	0	1
Total	13	21	34
	Column percentages		
Daylight	61.5	71.4	67.6
Dark	23.1	14.3	17.6
Dark/lighted	0.0	14.3	8.8
Dawn	7.7	0.0	2.9
Dusk	7.7	0.0	2.9
Total	100.0	100.0	100.0

3.3.2 Multiple-vehicle involvements

Table 42 shows the classification of multiple-vehicle crashes involving fire trucks by light condition and emergency use. Light condition for multiple-vehicle fatal involvements of fire trucks does not substantially differ by whether the fire truck was on an emergency run. A somewhat higher proportion of the crashes occurred in dark or dark/lighted conditions when the fire truck was on an emergency run, 38.9% to 27.3%, but sample sizes are not large enough to achieve significance. In terms of first harmful event, as might be expected, multiple-vehicle crashes of fire trucks almost always begin with a collision with another motor vehicle. All of the eleven multiple-vehicle crashes of fire trucks in nonemergency use were coded collision with a motor vehicle as the first harmful event; 94.4% (34 of 36) of the fatal crashes of fire trucks on an emergency run were initiated by a collision with another motor vehicle.

A comparison of Table 41 and Table 42 can be used to make inferences about the effectiveness of warning lamps, based on the rationale that the single-vehicle data are at most weakly affected by warning lamps, whereas the multiple-vehicle data are potentially affected by warning lamps. Any difference between the two tables in how crashes on emergency runs are distributed across lighting conditions could suggest an effect of warning lamps. Specifically, the effects of all vehicle lamps can be expected to be greater in low ambient light, and therefore both the positive and negative effects of warning lamps can be expected to increase in darker conditions. Thus, a comparison between relatively light and relatively dark conditions can be seen as analogous to a comparison between weaker and stronger warning lamps. If we assume that with there is a tradeoff between positive and negative effects with changes in the strength of warning lamps, then the comparison across light conditions might indicate what point on that tradeoff is represented by current lamps. However, the small sample sizes in this data set do not allow firm conclusions.

Table 42 Light Condition by Emergency Use
Multiple-Vehicle Crashes, Fire Trucks Only
FARS 1997-2001

	Emergency use		
Light condition	No	Yes	Total
Daylight	8	22	30
Dark	1	3	4
Dark/lighted	2	11	13
Dawn	0	0	0
Dusk	0	0	0
Total	11	36	47
Daylight	72.7	61.1	63.8
Dark	9.1	8.3	8.5
Dark/lighted	18.2	30.6	27.7
Dawn	0.0	0.0	0.0
Dusk	0.0	0.0	0.0
Total	100.0	100.0	100.0

Table 43 shows the types of collisions involving fire trucks. Manner of collision records the orientation of collision with a motor vehicle as first harmful event. (In the case of two crashes, the first harmful event did not involve a collision with a motor vehicle; those cases are coded not applicable here.) In the table, rear-end collisions are combined with same-direction sideswipes, and head-on collisions are combined with opposite-direction sideswipes.

Table 43 Manner of Collision by Emergency Use
Multiple-Vehicle Crashes, Fire Trucks Only
FARS 1997-2001

Manner of collision	Emergency use		
	No	Yes	Total
Not applicable	0	2	2
Rear-end/same dir. sideswipe	1	1	2
Head-on/opp. dir. sideswipe	3	4	7
Angle	7	29	36
Total	11	36	47
	Column percentage		
Not applicable	0.0	5.6	4.3
Rear-end/same dir. sideswipe	9.1	2.8	4.3
Head-on/opp. dir. sideswipe	27.3	11.1	14.9
Angle	63.6	80.6	76.6
Total	100.0	100.0	100.0

Note the dominance of angle collisions for fire trucks on an emergency run. Over 80% of the crashes occurred in that configuration, compared with 63.6% of nonemergency runs. The difference is not large enough to be statistically significant, but the size of the preponderance suggests that this possible association should be further investigated with a larger data set. Also note how few same direction crashes occur on emergency runs.

Multiple-vehicle emergency run crashes are also much more likely to occur at intersections than nonemergency run crashes. Table 44 shows the position of the crash relative to roadway geometry. The categories are somewhat self-explanatory, but there may be a benefit from a brief explanation. Intersection refers to the intersection of roadways. It means that the collision occurred within the boundaries of an intersection. Intersection-related crashes occur on an approach to an intersection and are judged to have been influenced by activity in the intersection. The driveway, alley category includes access points to the road that are not an intersecting roadway. And, of course, non-intersection encompasses all portions of the road that do not have intersections or other access points.

Table 44 Relation to Junction by Emergency Use
Multiple-Vehicle Accidents, Fire Trucks Only
FARS 1997-2001

Relation to junction	Emergency use		
	No	Yes	Total
Intersection	4	23	27
Intersection-related	1	1	2
Driveway, alley	1	1	2
Non-intersection	5	11	16
Total	11	36	47
	Column percentages		
Intersection	36.4	63.9	57.4
Intersection-related	9.1	2.8	4.3
Driveway, alley	9.1	2.8	4.3
Non-intersection	45.5	30.6	34.0
Total	100.0	100.0	100.0

Of all emergency crashes, 63.9% occur at an intersection, higher than for nonemergency crashes. Because of the small number of cases, this difference is not statistically significant. If verified, it would be practically significant, and it fits entirely with the disproportionate number of angle collisions for emergency use fire trucks.

3.4 Discussion

Of the three emergency vehicle types—police, ambulance, and fire—fire vehicles are the most likely to be on an emergency run when a fatal crash occurs. Fatal crashes of fire vehicles include particularly high proportions of single-vehicle crashes and rollover crashes. These results can probably be easily accounted for by the nature of fire trucks and of firefighting operations, in comparison to the vehicles and operations involved with the other two types of emergency vehicles.

Detailed examination of how the frequency of crashes involving fire trucks is affected by the interactions of number of vehicles, light condition, and whether or not the vehicle was on an emergency run may offer insight into the current effectiveness of warning lamps. However, the number of cases from the five years of FARS data examined here are too few to allow firm conclusions. Expanding the analysis to more years of FARS would be straightforward.

4 Fatal Pedestrian Crashes

This section provides analyses of cases in which firefighters are killed as pedestrians, based on a specialized database that covers all firefighter fatalities in detail (Roche, 2004). The main reason for including this form of data is that standard databases are not well suited for isolating these cases. For example, all pedestrians killed in road traffic should be included in FARS, but their identity as police, firefighters, or emergency medical personnel is not coded. Furthermore, although it might be possible to infer their professional roles from their vehicles (e.g., a police officer who is struck as a pedestrian is probably often near a police vehicle), those vehicles will not be associated with the crash in FARS unless they were actually involved as contact vehicles. For example, if a police officer is standing near a police vehicle and is hit by a passing truck, but the police vehicle is not struck by the truck, the FARS database will record the event as a crash involving a single vehicle (the truck) and a pedestrian; there will be no record of the presence of the police vehicle or of the fact that the pedestrian was a police officer.

4.1 Results

We believe we have reviewed all cases in which fire fighters were killed in crashes from 1999 through 2003. There were 98 total incidents, in which a total of 25 fire fighters were killed as pedestrians. In the 73 cases in which vehicle occupants were killed, nearly half (35) involved the vehicle rolling over. In 31 cases, the occupant who was killed was not belted.

Figure 5 shows the number of incidents, the number of fatalities, and the number of pedestrian fatalities by year. Table 45 shows the pedestrian cases by the type of the striking vehicle. Passenger cars were the most common. In 20 percent of the cases (5 of 25), the fire fighter was struck by a piece of fire apparatus.

For cases that occurred in 2001 through 2003, we classified each case as occurring in daylight or nighttime in terms of sun position. We used the limit of civil twilight—when the sun is 6 degrees below the horizon—as the boundary between day and night. Civil twilight is a traditional criterion for when there is enough natural light to engage in outdoor activities without artificial light (Owens, Francis, & Leibowitz, 1989). Figure 6 shows the number of pedestrian fatalities by day and night for 2001 through 2003. Most pedestrian fatalities occurred in daylight (9 of 15).

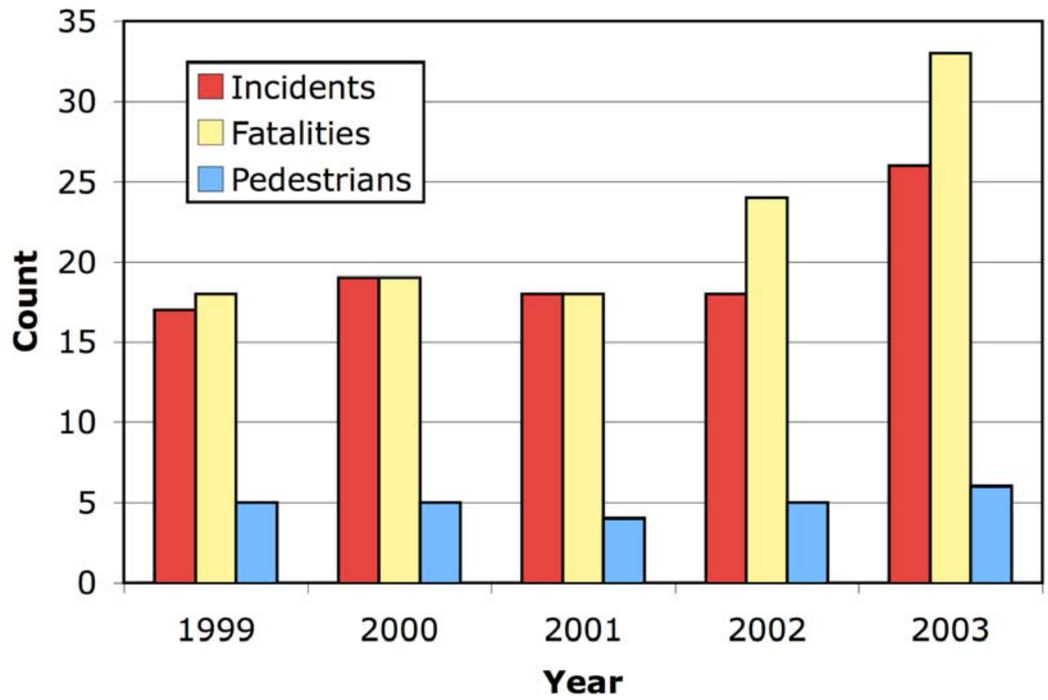

Figure 5. Counts of incidents involving firefighter deaths, number of firefighter fatalities in those incidents, and number of firefighter pedestrian deaths.

Table 45 Type of Vehicle Striking Pedestrian
in Fire Fighter Fatalities
1999-2003

Vehicle type	Cases
Passenger car	9
Light truck	4
Heavy truck	6
Fire apparatus	5
Unknown	1
Total	25

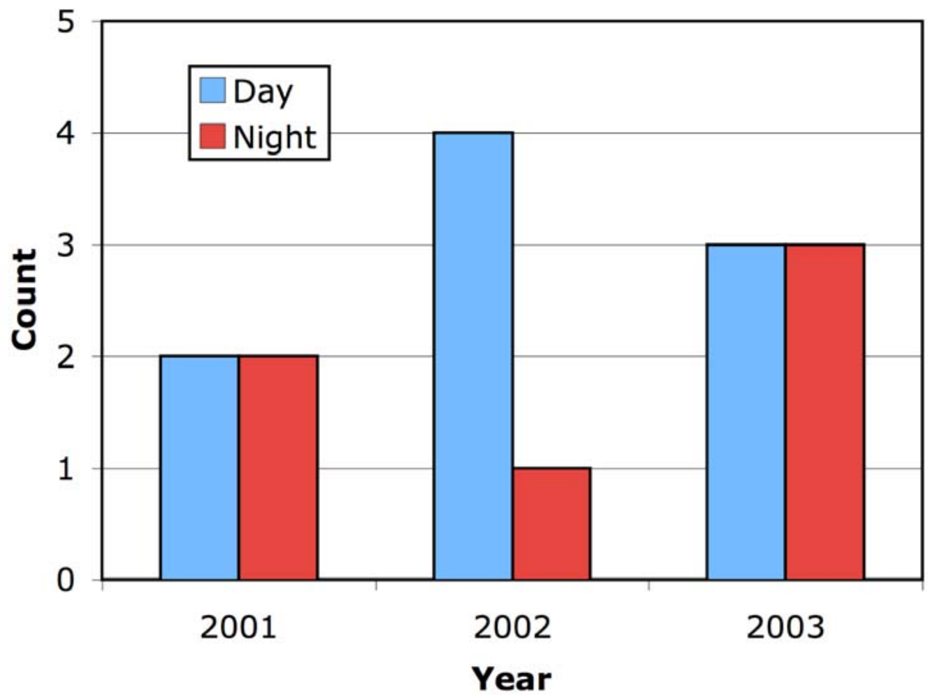

Figure 6. Counts of firefighter fatalities as pedestrians, by day and night.

4.2 Discussion

Pedestrian crashes are a substantial part of the problem of road traffic safety for firefighters; they account for about 26% of all fatal incidents. This appears to be consistent with the data reported by Clarke and Zak (1999). They reported that 16 firefighters were struck and killed as pedestrians in the six years from 1992 to 1997. This amounted to 18% of the total of 90 firefighters killed in transportation incidents, and 28% of the 57 firefighters killed in highway transportation incidents.

We did not obtain primary evidence about the artificial lighting conditions for these crashes, and we can make only limited independent judgments about the possible roles of warning lamps in these crashes. Light from headlamps or warning lamps is cited as a possible factor in some of these cases, but so are dark clothing and a lack of retroreflective markings. Although glare does diminish visibility distance in night roadway situations, the limits of low-beam headlamps are so severe that visibility distance is not adequate in most situations even in the absence of glare (Bhise, Farber, Saunby, Troell, Walunas, & Bernstein, 1977; Flannagan, Sivak, Traube, & Kojima, 2000; Perel, Olson, Sivak, & Medlin, 1983). It is therefore difficult to determine how changes in warning lamps might have affected these cases.

The number of pedestrian cases in this analysis is small. One reason for that is that fatal crashes are a small fraction of all crashes, even for crashes involving pedestrians. We can expect that for every fatal case there are many nonfatal cases, many of which probably took place under very similar circumstances and which could be used to make inferences about mechanisms just as well as the fatal cases. For information about nonfatal crashes involving emergency vehicles, it is possible to use a number of databases that include nonfatal crashes, such as the state databases discussed earlier in this report. However, in the case of nonfatal pedestrian crashes the options are much more limited. This is because, in contrast to the roles of emergency vehicles, the role of a pedestrian as an emergency professional is not coded in conventional databases. For the most serious cases, fatalities, special records such as those we used here are available. However, we are not aware of similar resources that could provide information about nonfatal cases.

5 Conclusions

5.1 Findings relevant to warning lamps

The crash data examined here provide several findings with possible implications for the effectiveness of warning lamps. The state databases yielded the most directly applicable findings. Emergency vehicles are involved in fewer angle crashes in the dark, consistent with the hypothesis that warning lamps are effective in preventing those crashes because the lamps are more salient in darker ambient conditions. In addition, changes in the warning lamps on fire trucks with the 1998 model year may have improved their safety effectiveness, as suggested by reductions in the number of crashes on emergency runs relative to those not on emergency runs. FARS data for fire trucks, classified by light condition and single/multiple vehicles involved, did not produce strong evidence for either missing warning lamps in the day nor for negative effects of warning lamps at night. However, the number of FARS cases examined was limited, and it would be straightforward to extend that analysis to more years of FARS data. Examination of PARs for crashes involving firefighting vehicles in Florida suggested that there may be a substantial number of multiple-vehicle crashes in which drivers of the nonemergency vehicles did not detect the emergency vehicle. Stronger warning lamps might be able to address that problem. Information from the specialized database for fatal firefighter road traffic crashes indicated that firefighter pedestrian deaths are a substantial fraction of all incidents in which firefighters are killed in road traffic (25 of 98 incidents). There were suggestions that warning lamps may have sometimes reduced the likelihood of drivers detecting and avoiding the pedestrian, but the likelihood of detection in those cases may have been low even without any negative effects of warning lamps.

5.2 Tentative recommendations

Although these results contribute to knowledge about how warning lamps may affect the risk of emergency vehicle crashes, that knowledge is still quite limited and suggestions for improvements in warning lamps must be considered tentative. For purposes of discussion and further investigation, more than for immediate action, we offer the following suggestions.

By increasing conspicuity, stronger warning lamps may reduce the risk of crashes in which another driver fails to detect an emergency vehicle. There does not appear to be strong evidence that stronger lamps would result in significant negative effects. Given the possibility that there is a tradeoff between the conspicuity of warning lamps and negative effects of those lamps, two options that may change that tradeoff seem worth considering: (1) Operational changes may reduce negative effects of lamps, thus allowing more effective warning lamps without increasing any negative effects. Details of such changes are beyond the scope of this report, but possible examples include retroreflective garments for pedestrians and better establishment of traffic flow past parked emergency vehicles. (2) Some warning-lamp variables (e.g., intensity and flash rate) may influence conspicuity and negative effects in ways that are not completely correlated. For example, data from Rumar (1974) suggest that this is true for the conspicuity and glare properties of different forms of flashing blue lights.

5.3 Possible future work

The results of this project lead to several possible approaches for further research to better understand how warning lamps affect emergency vehicle safety. First, although the crash data examined here did not provide clear evidence for negative effects of warning lamps, it is difficult to rule out the various effects that have been suggested. Furthermore, some of these negative effects cannot be effectively addressed by conventional, general purpose crash databases (specifically, potential negative effects that might result in crashes in which the emergency vehicle is not actually a contact vehicle in the crash). Therefore, it may be valuable to directly observe the behavior of other vehicles around an emergency vehicle engaged in emergency operation, either while in transit or while parked at an emergency site. This may be possible with any of various levels of instrumentation, ranging from simple video cameras to multiple-target radar units. Studies of this sort would not be expected to capture actual crashes, because those are so rare. However, it may be possible to observe changes in drivers' behavior that are predictive of crashes. For example, when an emergency vehicle is parked at a site, the speed and lateral clearance of passing vehicles could be measured.

Second, because of the importance of the possibility that warning lamps at night reduce the visibility of emergency personnel as pedestrians, and because further relevant crash data may be very difficult to obtain, this possible mechanism should be directly studied with human-performance field work. Much work has been done on the closely related issue of headlamp glare, and it would be straightforward to extend that work to warning lamps as glare sources. The current photometric characteristics of warning lamps have been developed with a series of formal demonstrations (Menke, 2005). That work, and studies using similar methods (e.g., Czajkowski, 2003; Wells, 2004), have been carefully executed and have provided much valuable information about the effects of warning lamps. However, given the complexity of the issues involved in evaluating all possible effects of warning lamps, and the continuing concern about possible negative effects of strong warning lamps, it may be beneficial to recheck some of the results of that work with alternative methods. Previous demonstrations have relied heavily on expert judgment, and even efforts to include a range of observers have been incomplete (Wells, 2004). Although such circumstances do not invalidate the previous work, the importance of the issue and the likelihood that no single experimental method is perfectly valid for predicting the effectiveness of warning lamps suggests that further work could be valuable. One major extension of the earlier work would be to use observers drawn from the population of normal drivers. That would include drivers with a variety of age and experience. It would also be valuable to supplement expert judgment and subjective opinion as much as possible with objective tests of drivers' ability to detect pedestrians in the context of different warning lamps.

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