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Influence of Color on Fire Vehicle Accidents

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Fire fighting equipment is predominantly red or red/white. However, this study reports that if other factors are the same, the probability of a visibility-related accident for a red or red/white pumper is greater than the probability for a lime-yellow/white pumper. Data from public safety departments' records regarding fire pumper runs and accidents that occurred over a four year period in a single city are reviewed and tabulated. It is shown that lime-yellow/white fire pumpers are significantly statistically safer than red and red/white fire pumpers.

PROBLEM

The National Safety Council reports that in 1988 motor-vehicle accidents were the sixth leading cause of death and the leading cause of accidental death (National Safety Council, 1991). During the period of this study (1984–1988) and continuing through 1990, the overall number of firefighter injuries has remained relatively constant. The National Fire Protection Association (NFPA) estimated that for the year 1990, the first year these data were compiled, there were 11,325 motor-vehicle accidents involving fire department emergency vehicles. Moreover, 1,300 firefighters were injured while responding to or returning from alarms (Karter & Le Blanc, 1991). The NFPA did not report on civilians killed or injured in those accidents.

Fire vehicle accidents are life-threatening and expensive, not only to those in the emergency vehicle, but also to those in other vehicles involved in these accidents. Beyond the immediate consequences of the accidents are the effects due to delayed or absent response, such as property and life loss at fire scenes. Injured firefighters may become eligible for compensation and disability payments. The community must repair or replace the damaged apparatus and adjust for temporary decreases in manpower and equipment. To provide some perspective, the cost of a typical fire department pumper is over $200,000, and an aerial ladder may cost more than two times that amount.

"The most costly accidents, in terms of [fire] vehicle damage and personal injury,

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occur at intersections . . . ." (Los Angeles Fire Department, 1983). Moreover, the New York State Department of Motor Vehicles reported that 70% of 1988 fire vehicle accidents were intersection accidents (New York State Department of Motor Vehicles, 1990).

Driving a vehicle may be described in part as multiple stimuli competing for attention and response of the operator. The avoidance of accidents, especially intersection accidents, is an objective of training for both civilian and fire service drivers. The use of luminant and audible warning devices serves to alert civilian drivers, presuming that an alerted driver may more readily avoid collision, or lacking avoidance, reduce the severity of the accident. Moreover, a common assertion within the fire service is that the efficacy of lights and sirens far outweighs the effect of fire vehicle color. However, if a color is attention getting, then it too should alert an inattentive or distracted driver.

BACKGROUND

In an almost unquestioned manner, fire vehicles have been painted red. We have found no research supporting the use of red color for visibility, safety, or psychological impact, yet it is pervasive in use. Published research for the fire service has supported converting from red vehicles to lime-yellow vehicles (Solomon, 1984).

A significant body of scientific research that pertains to visibility and color has been published. Included are:

1. The human visual system is most sensitive to the band of colors between the wave lengths of 510 nm and 570 nm, which encompasses greenish-yellow (or lime-yellow) and yellow (Southall, 1961).
2. The normal dark-adapted human eye is red blind. The bright-adapted eye is red weak (Southall, 1961).
3. Lateral peripheral vision for detecting yellows is 1.24 times greater than for red (Traquair, 1949).
4. Approximately 8% of males are red-green color deficient. One fourth of these men cannot see red light (Allen, 1970).
5. "Golden yellow . . . [is] the most easily visible color for both normal and color deficient groups under all testing conditions," (Lahr & Heinsen, 1959).

Additional research has focused on the camouflage effects of certain colors and combinations of colors:

1. The luminance of a well-worn highway and the luminance of its scenery are about the same. Light colors, which include white and yellow, are the most visible against this background (Allen, 1970).
2. Certain sets of colors, erroneously thought to enhance visibility, actually aid the breakup of the outline of vehicles and decrease the ability of detection (Allen, 1970; Leonard & Sleight, 1967). A common example is stripes or two-tone painting. Red and white combinations are rated as among the least visible. Yellow and black combinations are the most visible (Nathan, 1969).

A prior study demonstrated that the frequency of lime-yellow fire pumper intersection accidents is half that of red fire pumpers. That study encompassed nine cities in a one year period with an aggregate of 750,000 runs (Solomon, 1984).

In this study, the scope has been widened to include total moving, multiple-vehicle accidents involving fire pumpers. The specific category of intersection accidents is treated as a subtopic. Two-tone fire pumpers, red with a white upper cab and lime-yellow with white upper cab, are elements of this study. Resultant injury or vehicle requiring towaway is viewed as an indicator of accident severity.

PURPOSE AND RATIONALE

The purpose of this empirical study is to determine the effect of vehicle color on fire vehicle accidents. Three hypotheses of equal probability of an accident are tested against alternative hypotheses that fire pumpers painted red or red/white have an accident probability greater than fire pumpers painted lime-yellow/white. The hypotheses of equality are:

1. Fire pumpers painted lime-yellow/white have an accident probability equal to that of fire pumpers painted red or red/white.
2. In daylight with lights and siren operating, fire pumpers painted lime-yellow/white have an accident probability equal to that of fire pumpers painted red or red/white.
3. In intersections, fire pumpers painted lime-yellow/white have an accident probability equal to that of fire pumpers painted red or red/white.

METHOD

A retrospective study of fire pumper vehicle accidents in a single city provides statistics with respect to vehicle color. While the probability distribution of these accidents is Poisson, the statistical analysis, which employs Bayes' Theorem, is independent of distribution type. Since the number of accidents is small, accurate estimation of probability by vehicle color is suspect. Instead, the probability of a red or red/white fire pumper accident and the probability of a lime-yellow/white fire pumper accident are compared as a ratio. Supplementing the probability analysis, in addition to the accident types of the hypotheses, injury and towaway accidents are calculated on a run basis. Also, national vehicle crash data are contrasted with crash data for the city of Dallas in general and Dallas Fire Department pumpers specifically.

Data Sources

In the 1970s, the City of Dallas, Texas, began purchasing fire vehicles with lime-yellow body paint and white upper cab paint. This continued until the early 1980s. At that time, a switch was made to red body paint with white upper cab paint. Prior to the purchasing of lime-yellow/white vehicles, the fleet primarily consisted of all red vehicles.

From information supplied by the Dallas Fire Department, it is possible to determine for each year the number of lime-yellow/white fire pumpers, the number of red and/or red/white fire pumpers, and the total number of runs each color group performed.

The accident data detailing the Dallas Fire Department accidents are obtained from the motor-vehicle accident report forms filed with the Texas Department of Public Safety. These reports reflect all police-reported accidents involving the Dallas Fire Department for the dates included in the study.

National vehicle crash data are from the National Highway Traffic Safety Administration. The Dallas motor-vehicle accident data are from the Dallas Department of Transportation and the Texas Department of Public Safety. The Dallas Fire Department crash data are from information supplied by that organization and the Texas Department of Public Safety. The data gathered cover a four year period: October 1, 1984, through September 30, 1988.

Control of Variables

By studying a single urban fire department with vehicles of both color categories in service at the same time, the confounding of several variables was reduced and balanced. These include: weather conditions, law enforcement regulations, traffic densities, apparatus operation, driver training, vehicle inspection and maintenance, and length of run. All fire pumpers in the study were equipped with emergency lights and sirens. As a control of vehicle size, the fire vehicles used in the study exclude aerial trucks, ambulances, and chiefs' vehicles.

Analysis Procedure

In this study, multiple-vehicle and single-vehicle accidents are counted if the dynamics involve visibility between at least one civilian vehicle and a pumper. Accidents, in which the pumper is the only moving vehicle, are not counted if it is judged that the visibility of the pumper is not a factor. All accident reports are carefully reviewed to ascertain color. If fire vehicle color is not stated in the police officer's report, information such as identification number(s) and vehicle age is correlated with other Dallas Fire Department records in order to determine color.

An accident is said to be at an intersection if the diagram or narrative of the police officer's report indicates that the accident occurred in the intersection or as a result of passing through an intersection. Injuries and vehicle removal method are reported in specific sections of the police officer's report. Accident date and time from the police officer's report, and sunrise and sunset data from an almanac, are used to determine ambient skylight (day, night, or twilight). Moon-phase and cloud-cover are not considered.

The use of lights and siren is determined from analysis of the police officer's report: narrative section, factors and conditions section, and arrests and charges section. The objective of the statistical analysis is to establish whether or not the color of fire pumpers affects accident probability; not to determine the absolute accident probabilities. To do so, the unknown probabilities are compared by hypothesizing equality ($a = 1$, below), and then this hypothesized equality is discredited.

Two experiments are defined: One, *Er*, consists of red and red/white pumper runs. The other, *Ey*, consists of lime-yellow/white pumper runs. (A "run" is defined as a response to an emergency call during which a fire pumper is driven to an incident scene with audible and luminant warning devices activated, and subsequently returns without warning devices activated. Statistically, each run is considered to be a repetition of a "trial," resulting in an accident event or not-an-accident event.) *Er* has the quantity of *Nr* trials. *Ey* has the quantity of *Ny* trials. The probability of a red or red/white pumper accident in a single trial is designated *Pr*. The probability of a lime-yellow/white pumper accident in a single trial is designated *Py*.

A third combined experiment, *Eb*, has *Nb* trials (runs), $Nb = Nr + Ny$.

Let a lime-yellow/white pumper run be designated *Yrun*, and a red or red/white pumper run be designated *Rrun*. Assuming runs are random:

$$P(\{Yrun\}) = Ny / Nb$$
$$P(\{Rrun\}) = Nr / Nb$$

Let the occurrence of an accident be designated *Aacc*, a lime-yellow/white accident be designated *Yacc*, and a red or red/white accident be designated *Racc*. The conditional probability of a lime-yellow/white pumper accident given any one accident is written $P(\{Yacc\}|\{Aacc\})$. Given the independence of runs:

$$P(\{Yacc\}) = P(\{Yrun\}|\{Aacc\})$$
$$P(\{Racc\}) = P(\{Rrun\}|\{Aacc\})$$
$$P(\{Yacc\}|\{Aacc\})$$

$$= \frac{P(\{Yacc\} \cap \{Aacc\})}{P(\{Aacc\})} \text{ by definition}$$

$$= \frac{P(\{Yacc\})}{P(\{Yacc\}\ U\ \{Racc\})} \text{ by set theory}$$

$$= \frac{Py \bullet P(\{Yrun\})}{Py \bullet P(\{Yrun\}) + Pr \bullet P(\{Rrun\})} \text{ by Bayes' Theorem.}$$

For a real number $a > 0$, $Pr = a \bullet Py$.

Therefore:

$$P(\{Yacc\}|\{Aacc\})$$

$$= \frac{P(\{Yrun\})}{P(\{Yrun\}) + a \bullet P(\{Rrun\})}$$

$$= \frac{Ny / Nb}{(Ny / Nb) + a \bullet (Nr / Nb)}$$

$$= \frac{Ny / Nr}{(Ny / Nr) + a} \bullet$$

Letting $p = P(\{Yacc\}|\{Aacc\})$ *and* $r = Ny / Nr$, yields:

$$p = r/(r + a).$$

Now, if there are j accidents in total, the probability lime-yellow/white pumper accidents will occur exactly k times in j accidents is the binomial distribution:

$$P(\{k \text{ times}\}) = \frac{j!}{k!\,(j-k)!} p^k (1-p)^{j-k}$$

$$= \frac{j!}{k!\,(j-k)!} [r/(r+a)]^k [1 - r/(r+a)]^{j-k}.$$

The probability that the total number of lime-yellow/white pumper accidents does not exceed the observed number of lime-yellow/white pumper accidents, i, in the observed total number of accidents, j, is given by

$$P(\{0 \leq k \leq i\}) = \sum_{k=0}^{i} P(\{k \text{ times}\}) .$$

RESULTS

The calculated conditional probability that lime-yellow/white pumper accidents are as observed or fewer, given that a lime-yellow/white pumper accident is equally as probable as a red or red/white pumper accident, is presented in Table 1. Assuming the null hypotheses are correct, one would expect results this extreme in less than 5% of a large number of similar analyses. Therefore, it is probable that one color is safer than the other. As illustrated in Tables 1 and 2, the indication is that lime-yellow/white is safer than red or red/white in all categories. Moreover, Figure 1 shows that the probability of the observed numbers of lime-yellow/white accidents is maximum when the probability of a red or red/white accidents is more than three times the probability of a lime-yellow/white accident.

Red or red/white fire pumpers performed 153,348 runs, and lime-yellow/white fire pumpers performed 135,035 runs. According to the Texas Department of Public Safety, there were 28 accidents. Of these, 8 were discarded as not visibility related (in 6, a pumper struck a parked or unmoving car; in 2, a pumper struck a stationary object). Table 3 summarizes the characteristics of the included 20 accidents.

Note that for the 20 included accidents, 16 accidents involved red or red/white fire pumpers and produced 10 towaway and 7 injury accidents. The 4 lime-yellow/white fire pumper accidents produced 2 towaways and 1 injury accident. The data in Table 3 also show that daylight accidents account for 85% of all accidents and 86% of intersection accidents.

For the 11 intersection accidents involving red or red/white fire pumpers, 7 were towaway accidents and 5 were injury. The 3 intersection accidents involving lime-yellow/white fire pumpers had 2 towaways and none with injuries.

For the years encompassed by this study, Table 4 summarizes the estimated total motor-vehicle accidents as a function of miles driven for the United States and for the City of Dallas. Also presented are the City of Dallas estimated accidents per million miles for red or red/white fire pumpers and lime-yellow/white fire pumpers.

From these estimates, it can be reasoned that fire pumpers appear to be involved in significantly more accidents than motor vehicles as a whole. It is of interest that in Dallas the estimated accidents per million miles for red or red/white fire pumpers are more than 22 times (contrasting with lime-yellow/white fire pumpers at more than 10 times) that of the total of Dallas motor vehicles. The operation of fire pumpers, especially on emergency calls, can be interpreted to be very dangerous.

TABLE 1
PROBABILITIES OF OBTAINED RESULTS UNDER THE NULL HYPOTHESES FOR FIRE PUMPER ACCIDENTS

Equal LiY and RRw Probability Hypothesis (Accident Type)	Accident Counts		Probability of observed or fewer LiY accidents[1]
	LiY	Total	
All Types	4	20	0.013
Day with lights and siren[2]	3	14	0.048
Intersection	3	14	0.048

Key: RRw - Red or Red/White
LiY - Lime-Yellow/White

Notes:
1. These low probability values cast doubt on the validity of the hypotheses, thus implying that color is a factor in fire pumper accidents.

2. Presuming the ratio of lime-yellow/white runs to red or red/white runs is the same as it is for All Types.

TABLE 2
FIRE PUMPER VISIBILITY-RELATED ACCIDENTS BY COLOR PER HUNDRED-THOUSAND RUNS
(CITY OF DALLAS, TX; 10/84 - 9/88)

Accident Type	LiY	RRw
	(per 100,000 runs)	
All types	3.0	10.4
Day with lights and siren	2.2	7.2
Intersection	2.2	7.2
Towaway	1.5	6.5
Injury	0.7	4.6

Key: RRw - Red or Red/White
LiY - Lime-Yellow/White

CONCLUSIONS

With focus on the color of the fire pumpers and the number of fire pumper accidents, analyses were conducted on run and vehicle information supplied by the Dallas Fire Department and fire vehicle accident data from the Dallas police reports on file with the Texas Depart-ment of Public Safety. The effect of color on the risk of multiple-vehicle accidents or single-vehicle visibility related accidents involving fire pumpers has been assessed. The conclusion is that the likelihood of having a visibility-related multiple-vehicle accident or a visibility-related single-vehicle accident for a red or red/white fire pumper is greater than for a lime-yellow/white fire pumper. Perhaps it is more than three times as great.

Further, in those accidents involving a lime-yellow/white fire pumper, there is evidence that the likelihood of towaway or injury damage is less.

Limitations

To minimize the effects of confounding variables, a single city was used. However, this constricts the number of accidents. Future, broader-based studies are warranted. In addition, research is required on the effects of vehicle color on the remainder of the fire fleet and on highway vehicles in general.

Consequences and Implications

All fire pumpers in the study were equipped with emergency lights and sirens. In 80%

FIGURE 1

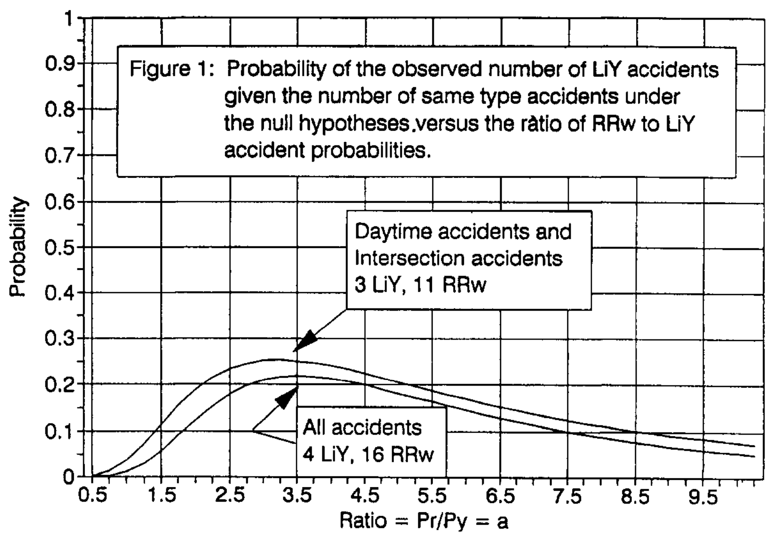

TABLE 3
CHARACTERISTICS OF FIRE PUMPER VISIBILITY-RELATED ACCIDENTS
(CITY OF DALLAS, TX; 10/84 - 9/88)

Index	Color	Intersection	Injury[1]	Towaway[2]	Day/Night[3]	Lights/Siren
1	Rw	Yes	Yes	Yes	Day	Yes
2	Rw	Yes	No	No	Day	Yes
3	Rw	Yes	No	Yes	Day	Yes
4	Rw	Yes	Yes	Yes	Day	Yes
5	Rw	Yes	No	Yes	Day	Yes
6	Rw	Yes	No	Yes	Day	Yes
7	Rw	Yes	Yes	Yes	Night	No
8	Rw	Yes	No	No	Day	Yes
9	Rw	Yes	Yes	Yes	Day	Yes
10	Red	Yes	No	No	Day	Yes
11	Red	Yes	Yes	No	Night	Yes
12	LiY	Yes	No	No	Day	Yes
13	LiY	Yes	No	Yes	Day	Yes
14	LiY	Yes	No	Yes	Day	Yes
15	Rw	No	Yes	Yes	Day	Yes
16	Rw	No	Yes	Yes	Day	Yes
17	Red	No	No	No	Day	No
18	Rw	No	No	No	Day	No
19	Red	No	No	Yes	Day	No
20	LiY	No	Yes	No	Night	Yes

Key: Rw - Red/White
LiY - Lime Yellow/White

Notes:
1. A towaway accident is defined as any vehicle involved in the accident reported as towed from the scene.
2. An injury accident is defined as person involved in the accident reported as injured.
3. No accidents occurred in twilight (dawn or dusk).

of all accidents and 93% of the intersection accidents, these devices were in operation. Augmenting these recognition aids, the superior visibility of lime-yellow color yields an earlier awareness of the fire pumper's presence by the civilian driver and results in a lower accident rate.

The Federal Aviation Administration has acted upon the results of earlier color studies and has issued mandates and recommendations for the use of lime-yellow on aircraft rescue and fire fighting vehicles (Federal Aviation Administration, 1986). In contrast, red continues to be the tradition of the municipal fire service despite greater risk and attendant increased cost.

The results extend the statement: "Because color and markings are passive techniques that do not require action on the part of the operator, they can serve to reduce risk even when the vehicle is not on an emergency response" (DeLorenzo, 1992).

Public health and safety are compromised not only in the public's direct participation in a fire vehicle accident, but also in the consequences of delayed response to an alarm should a fire vehicle be involved in an accident while enroute to an alarm. Fire department personnel's health and safety are directly threatened by vehicle accidents. Municipal expenditures include: lost time, wages and

TABLE 4
ESTIMATED ACCIDENTS PER MILLION MILES (1985-1988)

Category	Rate (per 10^6 mi)
National (all vehicles)	3.4
Dallas (all vehicles)	2.8
Dallas (RRw fire pumpers to and from alarms)	62.1
Dallas (LiY fire pumpers to and from alarms)	28.2

Key: RRw - Red or Red/White
LiY - Lime-Yellow/White

benefits, and the cost of supplemental personnel; health, life, and workers' compensation insurance costs; the costs of vehicle repair and premature replacement; and the expense of litigation resulting from fire vehicle accidents. Municipal liabilities might include the costs of extended disability or lost time expenses. Insurance rates are based on risk and competition. It can be expected that proven reduced risk could be part of a negotiation for reduced rates. Actuarial expectations for firefighters could also be expected to be adjusted based upon change in death rate experience.

The benefits of shifting the fire vehicle color paradigm from red to lime-yellow make it imperative that officers and officials responsible for purchasing these vehicles be encouraged to accept the change. The representatives of firefighters should be seeking safer vehicles for their constituents. Firefighters themselves should be educated as to the personal benefit gained in improved probability of safe transport to and from the alarm scene.

Realizing no single factor will halt all vehicle accident injuries and deaths, a composite of programs can have a strong impact. While we conclude that lime-yellow/white fire pumpers are safer to operate, from an epidemiology perspective, use of lime-yellow color may have significant beneficial highway implications beyond the fire service.

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