The Effects of Yellow Rectangular Rapid-Flashing Beacons (RRFBs) on Motorists' Yielding, Exit Lane Encroachment and Conflicts at Fire Station Exits

Erick K. Marmolejo
Western Michigan University

Follow this and additional works at: https://scholarworks.wmich.edu/dissertations

Part of the Experimental Analysis of Behavior Commons, Personality and Social Contexts Commons, and the School Psychology Commons

Recommended Citation

This Dissertation-Open Access is brought to you for free and open access by the Graduate College at ScholarWorks at WMU. It has been accepted for inclusion in Dissertations by an authorized administrator of ScholarWorks at WMU. For more information, please contact wmu-scholarworks@wmich.edu.
THE EFFECTS OF YELLOW RECTANGULAR RAPID FLASHING BEACONS (RRFBS) ON MOTORISTS’ YIELDING, EXIT LANE ENCROACHMENT, AND CONFLICTS AT FIRE STATION EXITS

by

Erick K. Marmolejo

A Dissertation
Submitted to the
Faculty of The Graduate College
in partial fulfillment of the
Requirements for the
Degree of Doctor of Philosophy
Department of Psychology
Advisor: Ron Van Houten, Ph.D.

Western Michigan University
Kalamazoo, Michigan
June 2011
THE EFFECTS OF YELLOW RECTANGULAR RAPID FLASHING BEACONS (RRFBs) ON MOTORISTS’ YIELDING, EXIT LANE ENCROACHMENT, AND CONFLICTS AT FIRE STATION EXITS

Erick K. Marmolejo, Ph.D.
Western Michigan University

The purpose of the current study was to explore the extent to which yellow rectangular rapid-flashing beacons (RRFBs) affected motorists’ yielding, exit-lane encroachment and conflicts at fire station exits. This study explored the use of RRFBs attached to sign prompts that alerted motorists to the presence of exiting emergency vehicles. These signs were activated only during an exit event. It was hypothesized that motorists would increase their frequency of safe and legal yielding in the presence of the RRFB intervention when compared to the absence of contextually activated RRFB units. This study was conducted in a midwestern town in front of a fire station known to have poor yielding compliance in the presence of exiting emergency vehicles. The results suggest that the RRFB intervention was successful at increasing yielding compliance to exiting emergency vehicles during the daytime and nighttime hours. The data suggest that enhancing yield signs with RRFBs may be an effective intervention to increase motorist-yielding compliance to exiting emergency vehicles.
ACKNOWLEDGMENTS

This dissertation would not have been possible without the dedicated contributions of several individuals. I would like to first thank my advisor, Dr. Ron Van Houten, for your patience in mentoring me and for opening my eyes to the opportunities in traffic research to make a difference in the human condition.

I'd next like to thank my research assistant team: Mee EE, Stephan Hansen, Chris Brumm, Chris Missias, and Lydia Baldwin. Without your dedication and perseverance we would have never turned 22,350 videos into data points that have the power to make a positive difference in the safety of our roadways.

I'd also like to recognize Rick Jones for providing the RRFB units used in this study, and the City of Mumdelein, Illinois for allowing this study to be conducted in its community.

Finally, to my mom; your unwavering confidence inspired me to drive to the finish line. We made it! Now on to the next challenge.

Erick K. Marmolejo
TABLE OF CONTENTS

ACKNOWLEDGMENTS .................................................................................................................. ii
LIST OF TABLES .......................................................................................................................... ix
LIST OF FIGURES ....................................................................................................................... x

CHAPTER

1. INTRODUCTION ..................................................................................................................... 1
   Arriving on Scene .................................................................................................................... 1
   Emergency Vehicle Crashes ................................................................................................. 3
   Fatality Data ......................................................................................................................... 3
   Police Fatalities .................................................................................................................... 4
   Firefighter Fatalities ............................................................................................................. 4
   Emergency Medical Services (EMS) ..................................................................................... 5
Community Impact of Emergency Vehicle Accidents .............................................................. 6
Emergency Vehicle Crash Profile ............................................................................................ 6
Emergency Vehicle Risk Mitigation ......................................................................................... 7
   Legislation Permitting Modified Traffic Behavior during Emergency Calls ...................... 8
   Legislation Obligating Civilian Motorists to Yield the Right-of-Way .................................. 10
   Flashing Lights ..................................................................................................................... 12
   Weaknesses of Flashing Lights ........................................................................................... 13
   Sirens and Audible Devices ................................................................................................. 14
Table of Contents—Continued

CHAPTER

Research Lab Data Collection and Analysis Apparatus ........................................... 30
Data Categorization Computer ................................................................. 30
Qualification and Categorization Keys ...................................................... 31
Data Coding Computer ............................................................................. 32
Back Up ........................................................................................................ 33

Experimental Design....................................................................................... 33

Experimental Conditions ................................................................................ 36
Baseline Condition – Daytime ......................................................................... 36
Treatment Condition – Daytime ....................................................................... 36
Baseline Condition – Nighttime ........................................................................ 36
Treatment Condition – Nighttime ..................................................................... 37

Independent Variables .................................................................................... 37

Dependent Variables and Operational Definitions ........................................... 39
Vehicle Yielding ............................................................................................ 39
Vehicle Failing to Yield .................................................................................. 39
Yield and Violation Types ............................................................................... 39
Partial Transect Violation .............................................................................. 40
Full Transect Violation .................................................................................... 40
Conflict Frequency ......................................................................................... 40
Time to Exit ..................................................................................................... 40
Time of Day ..................................................................................................... 41
Table of Contents—Continued

CHAPTER

Measurement of the Dependent Variables ......................................................... 41

Observation System Calibration ......................................................................... 41

Inter-observer Agreement (IOA) .......................................................................... 46

Research Assistant Training and Calibration ...................................................... 47

Research Assistant Training ............................................................................... 47

Data Collection Environment ............................................................................. 48

Calibration and Observer Drift ........................................................................... 49

HSIRB Approval and Informed Consent .............................................................. 49

3. RESULTS ....................................................................................................... 50

Average Motorist Yielding during Baseline and Treatment ............................... 50

Daytime and Nighttime Analysis ........................................................................ 50

Daytime and Nighttime Baseline ........................................................................ 50

Daytime and Nighttime Treatment ..................................................................... 50

Daytime: Baseline vs. Treatment T-test ............................................................... 51

Nighttime: Baseline vs. Treatment T-test ............................................................. 52

Overall Analysis .................................................................................................. 53

Vehicle Yielding and Not Yielding across Time Intervals ..................................... 55

Analysis of Yielders across Time Intervals ......................................................... 55

Cumulative Yielding – Daytime .......................................................................... 56

Cumulative Yielding – Nighttime ....................................................................... 57

Analysis of Non-yielders across Time Intervals during the Daytime and Nighttime Sessions ........................................................................................................... 59
Table of Contents—Continued

CHAPTER
Daytime Analysis of Non-yielders ........................................ 59
Nighttime Analysis of Non-yielders ........................................ 60
Yield and Violation Type Analysis ......................................... 62
Daytime Yield and Violation Type Analysis .............................. 62
Nighttime Yield and Violation Type Analysis ............................ 64
Time to Exit Analysis .......................................................... 65
Conflict Frequency Analysis .................................................. 66

4. DISCUSSION ........................................................................ 68
Yield and Violation Types ...................................................... 70
Time to Exit ........................................................................... 72
Behavioral Chain of the Yielding Response and Theoretical Mechanism of Action ................................................. 73
Behavioral Profiles of High and Low Probability Yields ............ 74
Strengths of the RRFB Intervention ......................................... 75
Strengths of the Study ............................................................ 77
Limitations ............................................................................. 78
Recommendations for Future Research ..................................... 80
Conclusion ............................................................................. 80

REFERENCES ......................................................................... 81

APPENDICES
A. Annotated Map of Research Location ................................. 88
B. HSIRB Approval Letter ....................................................... 90
### Table of Contents—Continued

#### APPENDICES

<table>
<thead>
<tr>
<th>Appendix</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>C.</td>
<td>Flowchart of the Observation and Data Processing Process</td>
<td>92</td>
</tr>
<tr>
<td>D.</td>
<td>Screenshot of the Data Collection Database</td>
<td>94</td>
</tr>
<tr>
<td>E.</td>
<td>Data Categorization Coding Prompts Poster</td>
<td>96</td>
</tr>
<tr>
<td>F.</td>
<td>Detailed Illustration of RRB Enhanced Yielding Signs</td>
<td>98</td>
</tr>
<tr>
<td>G.</td>
<td>Flowchart of RRFB Activation Chain and Timing</td>
<td>100</td>
</tr>
<tr>
<td>H.</td>
<td>Video Data Path Flowchart</td>
<td>102</td>
</tr>
<tr>
<td>I.</td>
<td>Still Frames of the Optical Detectors Video Output</td>
<td>104</td>
</tr>
<tr>
<td>J.</td>
<td>Video Coding Procedure Poster</td>
<td>106</td>
</tr>
<tr>
<td>K.</td>
<td>Vehicle Yield Line Poster</td>
<td>108</td>
</tr>
<tr>
<td>L.</td>
<td>Yield Prompt Line Poster</td>
<td>110</td>
</tr>
<tr>
<td>M.</td>
<td>Station Exit Poster</td>
<td>112</td>
</tr>
<tr>
<td>N.</td>
<td>Baseline Poster</td>
<td>114</td>
</tr>
<tr>
<td>O.</td>
<td>Time to Exit Poster</td>
<td>116</td>
</tr>
<tr>
<td>P.</td>
<td>Vehicle Yield Poster</td>
<td>118</td>
</tr>
<tr>
<td>Q.</td>
<td>Treatment Poster</td>
<td>120</td>
</tr>
<tr>
<td>R.</td>
<td>Photo of Activated RRFB Attached to Black-on-Yellow Fire Truck Sign</td>
<td>122</td>
</tr>
<tr>
<td>S.</td>
<td>Photo of Activated RRFB with Yield Prompt Arrow</td>
<td>124</td>
</tr>
</tbody>
</table>
LIST OF TABLES

1. Study Hardware and Software Materials List ........................................ 34
2. Table of Study Operational Definitions .................................................. 42
3. Inter-observer Agreement across Dependent Variables Table .................... 46
4. Average Yielding by Condition and Time of Day .................................... 53
5. 2x2 Factorial ANOVA: Condition vs. Time of Day .................................. 55
6. Vehicle Yielding by Time Interval: Daytime and Nighttime Sessions .......... 56
7. Vehicles Not Yielding by Time Intervals: Daytime and Nighttime .............. 59
8. Vehicle Yielding and Violation Type Frequencies and Percentages .......... 62
9. Time to Exit in Seconds ........................................................................... 66
10. Vehicle Conflict Frequency ..................................................................... 67
LIST OF FIGURES

1. Average motorist yielding in baseline (RRFB absent) and treatment (RRFB present) during the daytime and nighttime conditions ............................... 51

2. Cumulative yielding by time interval of motorists who yield regardless of condition, during the daytime session; baseline (absence of RRFB) and treatment (RRFB) conditions ......................................................................................................................................................................................... 57

3. Cumulative yielding by time interval of motorists who yield regardless of condition, during the nighttime session; baseline (absence of RRFB) and treatment (RRFB) conditions ......................................................................................................................................................................................................................................................... 58

4. Cumulative non-yielding by time interval during the daytime session; baseline (absence of RRFB) and treatment (RRFB) conditions ......................... 60

5. Cumulative non-yielding by time interval during the nighttime session; baseline (absence of RRFB) and treatment (RRFB) conditions ......................... 61

6. Profile of yield and violation types during the daytime condition across no-RRFB and RRFB conditions. ................................................................................................................................. 63

7. Profile of yield and violation types during the nighttime condition across no-RRFB and RRFB conditions. ................................................................................................................................. 64

8. Mean time in seconds for an emergency vehicle to exit the station’s apron and merge onto the roadway during daytime and nighttime sessions, across no-RRFB and RRFB conditions. ................................................................................................................................. 65
CHAPTER 1
INTRODUCTION

Serving as a First Responder has understandable risks. During an emergency, these professionals, which include firefighters, police, and emergency medical service (EMS) providers must put themselves in harm’s way and be first on the scene to provide emergency services. In order to provide timely emergency services, First Responders utilize specially outfitted vehicles to provide distinct first response services: Police—prisoner containment, weapons, safety equipment; Firefighters—fire suppression and hazardous materials remediation; and EMS—both basic and advanced life support equipment (BLS and ALS) and transportation to medical facilities. While these vehicles allow these First Responders to respond to emergencies quickly, they also introduce a significant risk to their operators and to the communities they serve. Risks exist for the First Responders, civilian motorists, pedestrians, and those receiving emergency services. A major risk to First Responders and civilian motorists results from events related to arriving on scene. First Responders must navigate a careful balance between their speed to the location of an emergency (known as “speed-to-scene”) and the enhanced dangers of navigating through traffic during emergency situations.

Arriving on Scene

The conventional wisdom on speed-to-scene suggests that the faster emergency responders can arrive on scene, the better the outcome for those involved in an emergency. In the pre-hospital care community this concept is often referred to as the
“golden hour,” which refers to treating a patient with traumatic injuries within 60 minutes of such an injury in order to maximize treatment outcomes (Lerner & Moscati, 2001). While speed-to-scene is quite logically linked to enhanced outcomes in the case of firefighting, where extended time to arrival on scene could result in increased property damage and threats to those around the fire, and law enforcement, where violent acts or civil unrest could be exacerbated in the absence of a timely response, the evidence is unclear in the case of medical emergencies (Solomon & Hill, 2002). Recent literature suggests that patients, even in the case of dramatic injury, may not have significantly improved outcomes if treated within the 60-minute window when compared to slightly longer timelines. However, due to the variability in emergency calls, it is generally accepted that the faster First Responders can arrive on scene to evaluate the situation, the better the outcome for all parties involved (e.g., those involved in an emergency, property owners, other people in the community, and those directly impacted geographically by the emergency) (Bledsoe, 2002).

Given that speed-to-scene is still accepted as an important consideration in the outcome of an emergency event, an unintended side effect has occurred. Modern emergency vehicles and their drivers respond with an implied urgency to emergency calls. This requires the drivers of emergency vehicles to make judgments on how quickly to respond to emergency situations and thus put themselves and others at a high risk for injury. One of the most significant risks that First Responders are exposed to before arriving on scene are automobile crashes (Solomon & Hill, 2002).
Emergency Vehicle Crashes

According to the Fatality Analysis Reporting System (FARS), the National Highway Traffic Safety (NHTSA) administration reported that in 1995, 20,000 accidents involved police cars, 3,300 accidents involved fire trucks, and 3,800 accidents involved ambulances nationwide (National Safety Council, 1997). These data indicate the frequency of accidents (adjusted for exposure) for traffic-related accidents involving emergency vehicles are significantly higher than civilian or commercial vehicles of similar size that are driven similar distances. In addition to the higher frequency of accidents, First Responders experience more severe injuries due to traffic accidents than civilian or commercial drivers. This could be due to the fact that depending on the vehicle; emergency personnel may not be restrained with a seatbelt (e.g., EMS personnel in the back of an ambulance and fire personnel outside of the main cabin of a fire truck) while responding to an event, and the likelihood that they could be traveling at a higher speed.

In a study conducted by the U.S. Fire Administration (2004) that surveyed all firefighter accidents from 1994 to 2001, it was found that 79% of firefighters killed during traffic collisions were not wearing restraints prior to the crash. This increased risk to non-restrained EMS personnel is also supported by the data analyzed by Maguire, Hunting, Smith, and Levick, in 2002.

Fatality Data

The evidence suggests that accident frequency and severity of injury is disproportionately high for First Responders. In addition, the number of fatalities that
occur as a result of emergency vehicle traffic accidents is also disproportionately high when compared to similar motor vehicle drivers. More detailed fatality data grouped by First Responder type is provided below.

Police Fatalities

In a study conducted in 2004 by the Rand Corporation (prepared for the National Personal Protective Technology Laboratory), it was discovered that during the period from 1990 to 2001, an average of 155 police officers were killed annually in the line of duty (Houser & Science, 2004). The most common causes of these fatalities were motor vehicle accidents and assaults (Houser & Science, 2004). A more recent study commissioned by the National Law Enforcement Officers Memorial (NLEOM) in 2008 found that motor vehicle accidents are still the leading cause of death for law enforcement officers (U.S. Fire Administration, 2009). The FBI reported that over the past 12 years, an average of one law enforcement officer has been killed each month in the U.S. as the result of traffic-related collisions. The most recent data indicates that of the 47 law enforcement officers accidentally killed in 2009, 34 (72.3%) of these deaths were caused by traffic-related incidents; a substantial increase over the 12-year average (FBI, 2009).

Firefighter Fatalities

Deaths related to active fire fighting still remain the most common cause of death for firefighters (79.6%). The second most common cause remains motor vehicle accidents that occur during the response to and the return from emergency scenes. A
study commissioned by the Federal Emergency Management Agency (FEMA) in 2002 reviewed firefighter fatalities from 1990 to 2000. The report indicates that motor vehicle crashes were responsible for 11.8% of all firefighter fatalities per 100,000 reported incidents (US Fire Administration & TriData Corporation, 2002). The most recent data available on firefighter fatalities, provided by the U.S. Fire Administration, reports that in 2009, 10.2% of all firefighter deaths were the result of motor vehicle accidents, indicating a relatively stable trend in firefighter fatalities due to motor vehicle accidents year after year (U.S. Fire Administration, 2004).

Emergency Medical Services (EMS)

Ground transportation fatalities among EMS workers are similarly high. A review of EMS fatalities caused by traffic accidents between the years of 1991 and 2000 revealed 300 crashes resulting in the death of 82 ambulance occupants and 275 deaths of occupants of other vehicles (U.S. Fire Administration, 2004). These data clearly illustrate the dangers faced by both EMS personnel and civilians in the vicinity of an emergency vehicle actively responding to an emergency.

Fatalities in EMS vehicles might be heightened due to the special circumstances of EMS personnel providing both transportation and life support services. EMS personnel, when restrained, are not able to access the entire patient or cabinets containing necessary life support equipment. Restraint systems in the patient compartment must be unbuckled in order for the EMS personnel to perform certain treatments (U.S. Fire Administration, 2004). Due to the need to be unrestrained in the patient compartment,
EMS personnel are placed at a much higher risk of fatality as a result of a motor vehicle collision (Kahn, Pirrallo, & Kuhn, 2001).

Individuals serving as First Responders and those in the vicinity of an emergency call are not the only individuals that are at risk of motor vehicle crashes with emergency vehicles. These incidents can also adversely affect the communities in which they occur.

Community Impact of Emergency Vehicle Accidents

Collisions with emergency vehicles are particularly dangerous to small communities that may have limited emergency response vehicles and emergency personnel. A collision with an emergency vehicle could limit that community’s ability to respond to future emergencies in the following ways: (1) the inability for that first response team to arrive on the scene of the emergency to which they were originally dispatched, (2) injuries to emergency responders could require time off work resulting in a staff reduction, and (3) mechanical damage to first response vehicles could prevent the vehicles from responding to future emergencies until the vehicles are repaired or replaced. Injury recovery, cost of repair, and time out of service due to motor vehicle collisions could place a community at an increased risk due to the reduced response capability (Solomon & King, 1995).

Emergency Vehicle Crash Profile

Solomon and Hill in 2002 provided a crash profile that summarizes crash data across multiple types of First Responder vehicles (police, fire, and EMS). They suggest that the typical emergency vehicle accident occurs under the following conditions:
[In] clear weather, on dry roads that are straight level, at an intersection, and
driving during daylight hours. Alcohol involvement is very slight, as are vehicle
defects. Apparent driver contributing factors are most heavily weighted towards
inattention to driving and failure to yield the right-of-way. (p. 115-116)

This crash profile indicates that environmental features, such as other drivers and
driving under modified traffic laws could be responsible for a significant number of
emergency vehicle crashes.

Emergency Vehicle Risk Mitigation

To facilitate fast response times, emergency vehicles have been given special
legislative permission to deviate from standard traffic laws in order to more quickly
arrive on scene. To mitigate the inherent risks that exist when vehicles depart from
accepted and predictable traffic patterns, First Responders and communities have
employed the following features to increase detectability and conspicuousness: (1)
legislation permitting modified traffic behavior during an emergency call, (2) legislation
obligating civilian motorists to yield the right-of-way to emergency vehicles, (3)
installation and use of flashing lights on emergency vehicles, (4) installation and use of
sirens and audible devices on emergency vehicles, (5) specialized vehicle colors, (6)
adorning vehicle silhouettes with retroreflective and phosphorescent materials, and (7)
road signs and markers. Each of these mitigation strategies are discussed in greater detail
in the following sections.
Legislation Permitting Modified Traffic Behavior
during Emergency Calls

The laws governing the behavior of emergency vehicles responding to emergency calls are unique to each state. Below is a segment of the Illinois state traffic law authorizing emergency vehicles to act outside the, “rules of the road” when responding to emergencies (Illinois state law was chosen due to the fact that the present study was conducted in the state of Illinois):

(625 ILCS 5/11-205) (from Ch. 95 1/2, par. 11-205)

Sec. 11-205. Public officers and employees to obey Act—Exceptions.

(a) The provisions of this Chapter applicable to the drivers of vehicles upon the highways shall apply to the drivers of all vehicles owned or operated by the United States, this State, or any county, city, town, district or any other political subdivision of the State, except as provided in this Section and subject to such specific exceptions as set forth in this Chapter with reference to authorized emergency vehicles.

(b) The driver of an authorized emergency vehicle, when responding to an emergency call or when in the pursuit of an actual or suspected violator of the law or when responding to but not upon returning from a fire alarm, may exercise the privileges set forth in this Section, but subject to the conditions herein stated.

(c) The driver of an authorized emergency vehicle may:

1. Park or stand, irrespective of the provisions of this Chapter;

2. Proceed past a red or stop signal or stop sign, but only after slowing down as may be required and necessary for safe operation;
3. Exceed the maximum speed limits so long as he does not endanger life or property;

4. Disregard regulations governing direction of movement or turning in specified directions.

(d) The exceptions herein granted to an authorized emergency vehicle, other than a police vehicle, shall apply only when the vehicle is making use of either an audible signal when in motion or visual signals meeting the requirements of Section 12-215 of this Act.

(e) The foregoing provisions do not relieve the driver of an authorized emergency vehicle from the duty of driving with due regard for the safety of all persons, nor do such provisions protect the driver from the consequences of his reckless disregard for the safety of others.

(f) Unless specifically made applicable, the provisions of this Chapter, except those contained in Section 11-204 and Articles IV and V of this Chapter, shall not apply to persons, motor vehicles and equipment while actually engaged in work upon a highway but shall apply to such persons and vehicles when traveling to or from such work. (Source: P.A. 89-710, eff. 2-14-97; 90-257, eff. 7-30-97.)

While legislation has allowed emergency vehicles to respond more rapidly to emergency situations, and knowledge about this legislation has become part of the standard driver training programs required to obtain a drivers license, it does introduce a unique contradiction. A civilian driver’s typical experience on the road is one of traffic flowing in predictable patterns where all vehicles observe the same traffic laws. However in the case of an emergency, the environment changes significantly and dynamically.
Depending on the position of a civilian vehicle and an actively responding emergency vehicle, motorists may need to encroach into intersections against a red light, creating novel driving environment that can lead to confusion and increased risk of accident. While legislation has made it legal for emergency vehicles to operate outside the standard "rules of the road," it has also inherently created an uncertain and unsafe environment for the operators of emergency and civilian vehicles alike. This issue is partially addressed by obligating civilian motorists to yield the right-of-way in the presence of an emergency vehicle in emergency response mode (e.g., lights and sirens). Laws related to the behavior of civilian motorists in the presence of a responding emergency vehicle are described in the next section.

Legislation Obligating Civilian Motorists to Yield the Right-of-Way

Drivers on U.S. roadways are required to take a written and practical test to demonstrate their understanding of traffic laws and their ability to safely operate a motor vehicle on public roadways. A major component of this written test is to assess the driver’s knowledge of conventional traffic laws commonly referred to as the "rules of the road." The following is an excerpt of the Illinois Rules of the Road publication relating to emergency vehicles:

Emergency Vehicles

When approaching a stationary emergency vehicle using visual signals, Illinois law requires motorists to yield, change to a lane away from the emergency vehicle and proceed with caution. If a lane change is not possible, reduce speed and proceed with caution.
When being approached by an emergency vehicle using audible and visual signals, Illinois law requires motorists to immediately pull to the right side of the road and allow the emergency vehicle to pass. In some cases a complete stop may be necessary to allow the emergency vehicle to pass. If stopped at an intersection with two-way traffic, remain stopped until the emergency vehicle passes.

If a driver fails to yield to an emergency worker or vehicle, and that failure results in a crash where an emergency worker is injured or killed, the driver may lose his/her driving privileges for a minimum of 90 days. (State of Illinois, 2010) (p. 27)

This excerpt demonstrates how states are attempting to support legislation that permits emergency vehicles to operate outside of civilian traffic laws by educating drivers of their obligation to yield in the presence of emergency vehicles. This obligation to yield the right-of-way is also supported through enforcement strategies where police provide financial penalties for failing to yield the right-of-way to emergency vehicles in “emergency mode.” While these enforcement strategies are universally applied, legislation and penalties alone are insufficient to occasion the safe yielding behaviors of drivers to emergency vehicles. The studies cited in the preceding sections of this paper indicate that despite the universal adoption of legislation and penalty strategies, accidents still occur. In the next section, vehicle-specific technologies and environmental changes that aid in alerting drivers to the presence of an emergency vehicle and signal the need to yield the right-of-way are described.
Flashing Lights

Flashing lights attached to emergency vehicles are used in an effort to alert others to the presence of the emergency vehicle so that they may yield the right-of-way. Flasing lights as a stimulus are most successful under the following conditions: (1) a light flash pattern appears against a high contrast background, (2) in the absence of other competing flashing lights (such as brake lights, street lights, road signs, seasonal decorations, or others), and (3) during clear atmospheric conditions with few competing light sources (such as bright sunlight or reflective glare) (Solomon & Hill, 2002).

When properly functioning, flashing lights are designed to (1) alert drivers to the presence of an emergency vehicle, (2) increase driver vigilance, (3) reduce driver speed, and (4) indicate a need to yield the right-of-way and/or avoid the responding emergency vehicle. Despite the widespread use of flashing lights on emergency vehicles, accidents still occur. In response to continuing emergency vehicle crashes, the National Fire Protection Association (NFPA) increased the number of flashing lights they recommended on fire vehicles; however, no research currently demonstrates the optimal number and types of lights for fire vehicles. In fact, some research suggests that increasing the number and intensity of lights often succeeds in creating a general state of arousal among motorists perceiving the flashes, but does not clearly indicate what the motorist should do to safely avoid the emergency vehicle (Howett & Law Enforcement, 1979).
Weaknesses of Flashing Lights

While flashing lights are standard equipment on all emergency vehicles, there are some significant limitations to their use as an effective stimulus that prompts a yielding response. First, the effectiveness of flashing lights is significantly reduced if the lights occur in the presence of other flashing lights or in the presence of bright atmospheric conditions. Daytime use of flashing lights can be rendered all but invisible to drivers when sufficient ambient light or glare is present in the driver’s environment. Nighttime also poses problems with the use of flashing lights. While flashing lights are particularly salient stimuli during nighttime conditions, this could adversely impact motorists driving at night. When a driver’s eyes have acclimatized to nighttime driving, the brightness of emergency flashing lights can adversely affect driver’s nighttime vision. This change in nighttime vision in the presence of bright flashing lights is referred to as “de-adaptation”. Depending on the strength of the flashing light and the duration of exposure, drivers may be temporarily unable to see, which has been attributed to many collisions with emergency vehicles. Another side effect of the use of flashing lights at night stems from some driver’s tendency to focus on the flashing lights instead of the road ahead or the desired behavior flashing lights should occasion—that of yielding the right-of-way/avoidance. This phenomenon puts parked emergency vehicles at particularly heightened risk (Solomon & Hill, 2002).

In general, while flashing lights do occasion an orienting response under optimal conditions, they do not clearly communicate how the motorist should react to the stimulus. Many of these weaknesses are addressed by combining flashing lights with sirens and audible devices. Sirens and audible devices are discussed in the next section.
Sirens and Audible Devices

Sirens and audible devices are designed to alert motorists to the presence of an emergency vehicle. The assumption is that drivers will be able to hear the warning soon enough to react and yield the right-of-way to the emergency vehicle. Sirens and audible devices such as air horns are most salient when there are few competing noises and the motorist to be alerted is not in a significantly sound-attenuated environment.

Emergency vehicle sirens and air horns produce about 115 dB of sound measured at 50 feet in front of the siren. Automobiles are manufactured with powerful sound-dampening materials to provide a more comfortable ride inside the cabin. The sound-dampening materials reduce the effectiveness of sirens and audible devices in alerting drivers to the presence of emergency vehicles. With an emergency vehicle 200 feet from an automobile and with that vehicle traveling at approximately 35 mph with the air conditioner running and radio on, the internal noise level could reach upwards of 90 dB compared to a siren or air-horn only able to produce 63 dB from the perspective of the driver in the vehicle. In this scenario, the sirens would be completely imperceptible to the driver and would not function as an effective-orienting stimulus until the emergency is within 25-50 feet (Solomon & King, 1995).

Other sound-emitting devices such as cell phones also reduce the ability of drivers to perceive sirens in their environment. Personal variables can also reduce the effectiveness of sirens as an orienting stimulus. For example, drivers with a reduced-hearing capacity are at a disadvantage. Another limitation of sirens is the reflecting properties of sound bouncing off surfaces around the driver. This reduces the directionality of the siren, which makes it difficult for drivers to perceive the origin of the
siren. Hatton in 1986 reported that by the time a siren can be detected by a motor vehicle operator, it’s often too late to stop at an intersection to avoid an accident.

Sirens and audible devices are quite commonly used but have recently been found to have some serious unintended side effects. They are suspected to contribute to the high rate of hearing loss observed in First Responder personnel. This clearly indicates that amplifying the audible sirens would not be an effective solution to increase vehicle conspicuity (see Reischl, Bair, & Reischl, 1979, and De Lorenzo & Eilers, 1991).

Sirens and the Adrenaline Response

Sirens have also been shown to increase adrenaline output in emergency vehicle operators and patients receiving care from EMS personnel. These respective effects may be contraindicated for different reasons. Increased adrenaline has been associated with faster driving speeds and reduced peripheral vision in EMS drivers. From a patient’s perspective, increased adrenaline can increase levels of anxiety and heart rate, which could adversely impact the patient’s condition. In fact, in some municipalities, sirens are not allowed when transporting patients that are experiencing a cardiac event. This reduction in the use of sirens has not been shown to significantly increase patient transit times or adversely impact patient outcomes (Solomon & Hill, 2002).

Addressing the limitations of flashing lights and sirens is a complicated undertaking. The traditional approaches of “brighter” and “louder” are reaching their practical limits. The next section briefly discusses this issue.
Practical Limits of Flashing Lights and Audible Devices

The historical trend has been to find ways to increase the conspicuousness of emergency vehicles by introducing more salient alerting stimuli such as louder sirens and brighter lights; however, this strategy is reaching its practical limit. Additional sound amplitude of audible alerts could lead to hearing loss in First Responders and increased light amplitude of flashing lights could become a distraction to drivers, rather than an effective stimulus that prompts a yielding response.

Theoretically, motorists would be able to clearly perceive the combination of flashing lights and sirens and, based on their experience and training, would then be prompted to safely engage in the correct response—yielding. However, modern roadways, with the increased congestion and driver distractors make such an “ideal case” a very rare case. More common is a responding emergency vehicle displaying lights and sounding sirens in a motorist’s environment that includes other cars, in-vehicle sound such as entertainment systems, cell phones, other passengers, and climate control systems, and other distractors that compete with the alerting stimulus. In order to overcome all of these distractors, the amplitude of auditory sirens and flashing lights would need to be raised to a level that could overwhelm and damage human sensory systems, cause more distraction than prompts to yield, and create nuisances in the communities in which they are used.

Differing Stimulus Conditions: Responder vs. Motorists

Another principle that appears to be important in understanding the interaction between the First Responder and civilian vehicle relationship is that that stimulus
conditions that the First Responders are under are quite different than those experienced by other motorists. In the passenger compartment of a responding emergency vehicle, the sounds of the siren and motivating conditions are acutely salient to the responding emergency personnel. However, the stimulus field that is controlling a motorist’s behavior is not the same. This significant difference in the environmental stimuli operating on First Responders and motorists lead to confusion and low compliance with signaling devices.

Other vehicle conspicuity strategies that don’t suffer from the limitations of flashing lights and audible sirens are described in the next section.

Vehicle Color

The classic red fire engine is a strong cultural symbol in the U.S., so much so that one major point of resistance to new research demonstrating other more effective color varieties is a commitment to tradition (Solomon & Hill, 2002). The National Safety Council (NSC) estimates that accidents involving red or red and white fire vehicles occur at the rate of 62.1 accidents per million miles. This is compared to the accident rate of vehicles of similar size such as commercial trucks, which have an accident rate of 21.6 accidents per million miles (Solomon & King, 1995). One proposed explanation for the increased rate of accidents in red and red and white fire vehicles could be explained by the color red itself. Solomon and King in their 2002 article, “Why Fire Vehicle Color is a Safety Issue,” point out three critical contributing factors implicating red as a sub-optimal color for increasing the detection of emergency vehicles: (1) due to the color acuity characteristics of the human eye, under most circumstances, the color red is difficult to
perceive, even in daylight, (2) under lowlight conditions, all humans are practically, "red blind," (3) red-green color blindness affects over 8% of adult males (this group as a whole has more accidents as similar driving groups with normal color vision) (Lardelli-Claret, et al., 2002).

These findings were confirmed by a DuPont™ study that measured fire department red (DuPont™ Imron® 674) during daytime and nighttime conditions compared to a lime-yellow paint variety (DuPont™ Imron® 7744-1) under the same conditions. DuPont’s results indicated that the lime-yellow color has a peak eye response 4.9 times greater than the fire department red color during the daytime, and approximately 93 times greater at night. These results were cross referenced with crash data which indicated that red vehicles were involved in twice as many accidents as lime-yellow ones. De Lorenzo and Eilers (1991) and Solomon and Hill (2002) indicate that vehicle color could be a critical factor in emergency vehicle crashes.

Vehicle color is not the only way that the external appearance of an emergency vehicle can assist in increasing the detectability of emergency personnel. Adornments can be applied to emergency vehicles that can also enhance their conspicuity. These adornments are discussed in the next section.

Vehicle Silhouette, Retroreflective, and Phosphorescent Materials

The large size of emergency vehicles in comparison to other vehicles on the road does enhance the vehicles detectability; however, emergency vehicle detectability can be further enhanced with the use of retroreflective tapes and phosphorescent materials. These tapes and materials are most effective when they enhance the overall silhouette and
contours of an emergency vehicle. However, for these tapes and materials to be effective, they require a strong light source, such as headlights, and are most effective at night. They function by directing light emitted from headlights back to their source and by maintaining luminescence after being stimulated by a light source (i.e., glowing). Data derived from studies of paint used to color the bodies of emergency vehicles also applies to these retroreflective and phosphorescent materials. Florescent lime-yellow is the most detectable color at night. These materials are most effective when they outline the contours of the vehicle in a simple pattern. Complex patterns can introduce confusing stimuli to drivers that increase the overall reaction time to the terminal response (e.g., yielding, speed reduction, or avoidance) when prompted by the stimulus, which is counter to the intended goal of these vehicle adornments (Solomon & Hill, 2002).

Thus far in this review we have discussed legislative approaches to increasing yielding to emergency vehicles, vehicle-specific interventions including flashing lights, sirens and audible devices, vehicle color, and silhouette and adornments. The next portion of this review presents a brief summary of environmental interventions such as road signs and markers and the use of roadside yellow rectangular rapid-flashing beacons (RRFB) that are designed to increase yielding to emergency vehicles.

Road Signs and Markers

Vehicle road signs are designed to provide antecedent stimuli such as prompts and rules that provide drivers with information on changing road conditions (e.g., sharp turns, curvy roads, approaching intersections, and others) and local ordinances (e.g., speed limits, cell phone laws, and enhanced penalties for reckless driving in special zones).
They are also used to alert drivers to dynamic road conditions such as exiting emergency vehicles, weather-related issues, construction zones and other potentially hazardous road and traffic conditions.

In a series of studies conducted by Van Houten et. al., it was identified that road signs are most effective in terms of driver compliance when specific (e.g., “KEEP RIGHT EXCEPT TO PASS”), less specific (e.g., “SLOW TRAFFIC KEEP RIGHT”), and salient (i.e., clearly visible with a high contrast to the surrounding environment) (see Van Houten & Van Houten, 1987; Van Houten, 1988; Van Houten & Malenfant, 1992; and Van Houten, McCusker, Huybers, Malenfant, & Rice-Smith, 2003).

Road signs have been shown to control multiple driver behaviors and increase driver safety in the areas of seatbelt compliance, yielding to pedestrians, driver vigilance, and vehicle speed (see Van Houten & Malenfant, 2004). While environmental prompts have reliably demonstrated control of motorist behavior, they do have some disadvantages, which are discussed in the next section.

Weaknesses of Road Signs and Markers

One of the primary weaknesses of road signs and markers is that they are often static and non-contextual. For example, a road sign will warn of pedestrians ahead in the presence and absence of pedestrians. This prompting in the absence of the relevant stimuli could lead to a decrease in the stimulus control road signs have over the behavior of drivers (see Van Houten, Ellis, & Marmolejo, 2008, and VanWagner, in press). Attempts to address this issue of a lack of context have yielded some interesting data
(e.g., Van Houten, et al., 2008) that suggest that signs and markers that alert the driver only in the presence of a stimulus are more effective than static signs and markers.

Rectangular Rapid-flashing Beacons (RRFBs)

A new technology that is being used to contingently alert drivers to relevant conditions is called a yellow rectangular rapid-flashing beacon (RRFB) and has been shown to be effective in controlling motorist yielding to pedestrians and driver speed. The RRFB is an inexpensive and effective device that employs yellow light emitting diodes (LEDs) that are similar to flashers found on police vehicles. When these devices were mounted to pedestrian crossing signs and contingently activated (illuminated) when pedestrians were actively crossing the road, it was found that the RRFB produced a large increase in the percentage of drivers yielding to both staged (crossings conducted by researchers) and non-staged (crossings conducted by members of the community) crossings (Van Houten et al., 2008).

In a similar study conducted in 2009 by Shurbutt, Van Houten, Turner, and Huitema, the differential effects of using two RRFB devices compared to four RRFBs were assessed in terms of their effectiveness in increasing driver yielding to pedestrian crossings. In this study it was found that the use of two RRFBs resulted in a significant increase in motorist yielding over baseline (no RRFB and just a static sign) from 18% yielding during baseline to 82% during the two-RRFB condition. The four-RRFB condition resulted in safe yielding compliance of 89%.

In a study conducted by Van Wagner, Van Houten, and Betts (in press) the use of an RRFB was shown to be effective in reducing motorist speed on a curved roadway. The
RRFB was attached to a 35 mi/h speed limit sign and was automatically activated when motorists were driving at speeds above 41 mi/h and were within 200–300 feet of the device. This study showed significant reductions in motorist speed with the most significant effects in drivers driving well over the speed limit (drivers driving at or under 41 mi/h did not experience the RRFB condition).

Despite the success in using RRFB technology in pedestrian crossings and to control driver speed, no studies have yet used this technology to address the issue of motorist’s yielding to exiting emergency vehicles. However, one common thread in these recent studies that have utilized RRFB technology as a prompting contingency is the application of sound behavior principles in the research design, application of the independent variable, and explanation of the results. Behavioral principles have a long history of being successfully applied to motorist safety behavior. A brief list of references from the behavioral literature that address many areas of motorist safety are presented in the next section.

Applications of Behavioral Interventions to Improve the Safety of Motorist Behavior

Applications of behavioral principles to driver behavior and traffic safety have been successfully documented in the literature. Behavioral principles have been successfully used in the following areas: (1) seat belt compliance (see Geller, Casali, & Johnson, 1980; Geller, Paterson, & Talbott, 1982; Geller, Davis, & Spicer, 1983; Malenfant & Van Houten, 1988; Williams, Thyer, Bailey, & Harrison, 1989; Van Houten, Malenfant, Zhao, Ko, & Van Houten, 2005; Clayton, Helms, & Simpson, 2006; and Clayton & Helms, 2009), (2) speed reduction (i.e., compliance with posted speed
limits) (see Van Houten, Nau, & Marini, 1980; Van Houten & Nau, 1981; Van Houten & Nau, 1983; Auerbach, Morris, Phillips, Redlinger, & Vaughn, 1987; Roqué & Roberts, 1989; Ragnarsson & Bjorgvinsson, 1991; Thomas, 1999; and Anderson & Kirkpatrick, 2002), (3) yielding to pedestrians (see Van Houten, Malenfant, & Rolider, 1985; Van Houten, 1988; Huybers, Van Houten, & Malenfant, 2004; and Van Houten & Malenfant, 2004), and (5) many others including increasing safe driving of delivery drivers (see Ludwig & Geller, 1991).

Despite the well-documented history of successful behavioral interventions in the area of traffic safety, an extensive review of the *Journal of Applied Behavior Analysis* and the *Journal of Organizational Behavior Management* did not identify a single study investigating increasing yielding to emergency vehicles. The next section describes how the present study extends the existing research.

**Extending the Existing Research**

While the preceding countermeasures have had a positive cumulative effect on reducing accidents with emergency vehicles, accidents still occur regularly, with accidents at intersections most prominent. These accidents are often due to vehicles failing to yield right-of-way (Massie, Campbell, & Blower, 1993). The present study seeks to fill this gap by utilizing a combination of behavioral techniques and RRFB-based interventions demonstrated in other areas of the behavioral and traffic safety research to address the problem of civilian vehicles yielding right-of-way to emergency vehicles.

The present study seeks to extend the research on improving vehicle yielding to emergency vehicles by testing sign-based environmental intervention consisting of a
contextually activated sign that uses RRFBs, precise timing, and is only illuminated during the presence of an exiting emergency vehicle to increase vehicle yielding to exiting emergency vehicles. This study extends the research in two ways. First, by extending the application of RRFBs to increasing motorist’s yielding to exiting emergency vehicle, and second, by utilizing behavioral principles in the interpretation of the effectiveness of the independent variable. The next section describes the experimental methodology used to conduct the experiment.
CHAPTER 2

METHOD

Research Location

The present study was conducted in front of a fire station that intersects a four-lane road and serves a diverse midwestern community of over 30,000 people. This fire station accommodates six emergency vehicles and a combination of six to twelve firefighters and emergency medical personnel. It is also the site of the community’s Emergency Operations Center (EOC), a backup communications center, and a police substation. The station is in operation 24 hours a day, seven days a week.

The fire station’s apron (e.g., driveway) intersects at a perpendicular angle with a heavily traveled, four-lane road, running in the north and south direction. The road has an average daily traffic flow (ADT) of 29,600 cars and is severely impacted during typical rush-hour time periods. The fire station is outfitted with three roll-up doors allowing up to three emergency vehicles to exit the station simultaneously.

This site was selected for the present study because of the community’s concerns with near-conflicts due to motorists failing to yield during emergency exits. The site was also chosen due to the approval of the city engineer and the good match between the video-based observational methodology and the topography of the fire station (see Appendix A for an annotated map of the research location).
Participants

Participants of the present study included all motorists who traveled in a northbound or southbound direction on South Lake St. in Mundelein, Illinois, which is a public roadway perpendicular to the fire station being studied. Observations were collected only when emergency vehicles were exiting the station during an emergency call (exits for other reasons, e.g., refueling or maintenance, were not considered). The study also included all emergency vehicles exiting the fire station during emergency calls.

Informed Consent

Due to the covert nature of the data collection system and the fact that observations were conducted of motorists on a public roadway, no informed consent or study assent was required. The communities' fire chief provided authorization for the participation of the emergency personnel and the city engineer provided authorization for the installation of the observation equipment and intervention devices. See Appendix B for HSIRB approval under exempt status.

Observation Method

Data for the study were collected using two wirelessly connected Internet protocol (IP) cameras aimed at the four-lane roadway perpendicular to the fire station's apron. These cameras were mounted under the eave of the fire station's roof and were enclosed in sealed, climate-controlled enclosures that made the cameras difficult to view by study
participants. The cameras’ data were fed to a computer system equipped with optical
detection software, which ran through the following phases of data processing:

Capture Phase

Upon exit of an emergency vehicle, the optical detector would be triggered. The
computer would then begin recording the event beginning approximately 10 seconds
before the optical detector was triggered, and lasting for approximately 30 to 40 seconds.
This 10-second pre-event record was designed to allow the researchers to view the entire
exit event—not just at the point the optical sensor was triggered. To accomplish this, the
computer was programmed to constantly capture video data and only record the data to
the hard drive in the event of an optical sensor trigger (see Appendix I for a still frame of
the video capture output).

Data Qualification Phase

The resulting video file was then automatically transferred over to the data
qualification phase where the video was qualified by the following criteria: (a) Did the
video meet the criteria for an “Emergency Exit”, (b) Is the video file sufficient in duration
to view the entire exit event, and (c) Is the video sufficiently clear to be analyzed along
the dimensions of the dependent variables? (See Table 2 for a list of operational
definitions.) If the answer to each of these questions was yes, the videos were then
qualified for categorization and passed to that phase. This data qualification was done by
transmitting the videos to the student researcher’s cell phone for visual analysis, if a
video didn’t meet criteria the student researcher could use some automated computer
scripts that automatically filtered out videos from the data set that did not meet the time requirements to view a complete exit event.

Categorization Phase

The categorization process takes qualified videos and organizes them into three major categories: (a) emergency exits without traffic, (b) emergency exits with traffic, and (c) false-positive videos (often due to false triggers of the optical detection system by reflections and non-emergency vehicles entering the apron). Those videos identified as emergency exits with traffic were then passed to the analysis phase. All other videos were archived and not considered in the analysis.

Analysis Phase

The analysis phase only considered “events of interest” (emergency vehicle exits in the presence of traffic). In this phase, trained human data collectors evaluated the events of interest across the dimensions of each dependent variable. The identified videos and dependent variables were then stored together in a customized database. (See Appendix C for a flowchart of the observation and data processing process. Also, see Appendix D for a screenshot of the data collection database.)

Apparatus

Fire Station Data Collection Apparatus

All video clips for the study were captured digitally using two Panasonic® BL-C111A IP cameras aimed at the northbound and southbound lanes of the street
perpendicular to the station’s apron. The cameras were mounted under the eave of the fire station and enclosed in a Lorex® weatherproof enclosure that provided defrosting functionality during the winter and cooling during the summer months. The two cameras were wirelessly connected to an Apple® Macintosh Power Mac G4 desktop computer running Mac OS 10.5.7 through an Apple® Airport wireless router. The cameras’ digital video feed was handled by EvoCam software version 3.6.6, which provided the optical detection and video storage functionality. The entire research apparatus with the exception of the remote cameras were stored inside the fire station’s communications closet and connected to an APC® uninterruptible power supply to prevent downtime due to power fluctuations.

Once the optical detector was triggered and the EvoCam software recorded an event, (a) a JPEG digital still image of the video file was taken and (b) uploaded to a custom-made website and (c) sent as an email attachment to an email address set up for the research study. All data, both video and still photography, sent through the Internet were encrypted using an AES 128-bit key, thus protecting the data from unauthorized access. The combination of email and website depictions of the data allowed the researcher to calibrate the system remotely. In the case in which the system needed to be calibrated, Apple® Remote Desktop version 3.3.2 was used to remotely control the research computer and adjust the sensitivity of the optical detector, refocus or reorient the cameras, or change any of the automation rules for data handling. Remote control of the research system was made possible via a dedicated business class 5 Mb up 5 Mb down Internet connection provided by Charter Communications Inc. This network connection also made remote viewing of live camera images possible via a website and portable
handheld devices like the Apple® iPhone (see Appendix G for a graphical flowchart of the video data path).

All data collected via the remote research computer were automatically backed up daily at 3:00am EST (this time was selected due to the low frequency of emergency calls during this time) to a dedicated internal hard drive installed in the research computer’s case off site, using Apple’s Mac web service. The total backup time took approximately 45 minutes on average.

Research Lab Data Collection and Analysis Apparatus

Technology was installed in Dr. Ron Van Houten’s Applied Behavior Analysis Lab at Western Michigan University to interface with the remote data collection system. This installation consisted of two Apple® Mac mini computers connected to the university network running Mac OS X 10.5.7 that were used for both data sorting (qualification and categorization phases) and data coding (analysis phase).

Data Categorization Computer

On a predetermined weekly schedule, the data-categorization computer would receive a package of data from the remote data collection computer. The data categorization computer used Keyboard Maestro version 4.1 and Hazel version 2.3.5 to quickly tag video files and sort them based on the extent to which they matched the operational definition for an event of interest. Keyboard Maestro allowed the researchers to assign keys on the keyboard that would then color and tag the video files based on their appropriateness for the research study. The Hazel software then evaluated those tags
and automatically sorted the videos into separate directories. The keyboard keys and their corresponding functions are described in the next section.

Qualification and Categorization Keys

\( F16. \)

This key was pressed if the selected video demonstrated an emergency vehicle exiting with lights flashing in the presence of traffic. This key tagged the video as an event of interest and color the video file name red. Video files considered events of interest (after a 10-second delay) were then passed to the second Apple Mac mini, which was responsible for data coding (the analysis phase).

\( F15. \)

This key was pressed if the selected video demonstrated an emergency vehicle exiting with lights flashing in the absence of traffic. This key would tag the video as a no traffic exit and color the video file name yellow. Video files considered no traffic exits (after a 10-second delay) were sorted to a separate directory to be used for calibration of the qualification categorization system.

\( F14. \)

This key was pressed if the selected video did not demonstrate an emergency vehicle exit—a Type I Error. This key would tag the video as a Type I Error and color the video file name grey. Video files considered Type I Errors (after a 10-second delay) were
sorted to a separate directory to be used for calibration of the qualification categorization system.

F13.

This key was pressed if the research assistant made an error. Pressing this key would remove the tag and color code from the selected video files. This functionality, including the 10-second delay, was included during pilot testing to address keystroke errors (see Appendix E for a job aid describing the keys and their functions used by the research assistants).

Data Coding Computer

The data-coding computer received all red file tagged events of interest from the data-sorting computer. These files were then loaded into a custom FileMaker® Bento database where the videos were analyzed based on the dimensions of the study’s dependent variables (see Appendix C for a screenshot of the database). Research assistants selected videos from the “new data” section of the database and then viewed and coded the video within the same page of the database. Once the coding procedure was complete, the database automatically sorted that video as complete and removed it from the new data list. The database also provided functionality for the research assistants to request a “second opinion.” By checking this field in the database, the video under analysis went into a special section of the database that was then discussed during the next research assistant meeting. The database was also used to collect inter-observer agreement (IOA) by randomly selecting 20% of the coded data and presenting those data
to two different research assistants. Data from the videos that had completed analysis were then exported into a spreadsheet for statistical and visual analysis.

Back Up

Data from both the data-sorting computer and data-coding computer were backed up on a daily schedule at 1:00am to an externally connected dedicated backup hard drive and simultaneously off-site using Apple's .Mac Web service. The total backup time took approximately one hour and 10 minutes on average. Completed backups triggered an email to the primary investigator indicating the status of the backup (see Table 1 for a full list of materials and approximate costs).

Experimental Design

A replicated AB design was utilized to test the effectiveness of the independent variable on the various study dependent variables. This design was necessary due to limitations in reversing the independent variable and the nature of the field conditions at the research site. The first AB was conducted during the daytime, followed by a second AB conducted during the nighttime hours. The replication was conducted at the same location using the same apparatus, experimental procedure, and over the same time period.
Table 1

*Study Hardware and Software Materials List*

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
<th>Approx. Cost</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Panasonic BL-C111A</td>
<td>IP Cameras</td>
<td>$229 ea.</td>
<td>Panasonic Inc.</td>
</tr>
<tr>
<td>Lorex ACC1721HB</td>
<td>Weatherproof Camera Enclosure with Built-in Heater and Blower</td>
<td>$99 ea.</td>
<td>Lorex Inc.</td>
</tr>
<tr>
<td>Apple AirPort Extreme</td>
<td>Wireless Internet router connecting the cameras to the optical detection software.</td>
<td>$199</td>
<td>Apple Inc.</td>
</tr>
<tr>
<td>Apple PowerMac G4 &amp; Display</td>
<td>Onsite research computer running the optical detection software</td>
<td>$999</td>
<td>Apple Inc.</td>
</tr>
<tr>
<td>APC Back-UPS ES</td>
<td>Uninterruptible power supply for computer &amp; router</td>
<td>$49</td>
<td>APC Inc.</td>
</tr>
<tr>
<td>Apple Mac Mini</td>
<td>Data sorting &amp; analysis computers</td>
<td>$599 ea.</td>
<td>Apple Inc.</td>
</tr>
<tr>
<td>LaCie Rugged Hard Disk</td>
<td>Data backup drive</td>
<td>$149</td>
<td>LaCie Inc.</td>
</tr>
<tr>
<td>500 GB</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 1—Continued

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
<th>Approx. Cost</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mac OS X 10.5.7</td>
<td>Observation computer’s operating system</td>
<td>$79</td>
<td>Apple Inc.</td>
</tr>
<tr>
<td>Safari version 4.04</td>
<td>Web interface for camera</td>
<td>Free</td>
<td>Apple Inc.</td>
</tr>
<tr>
<td>Apple Remote Access</td>
<td>Remote access software</td>
<td>$299</td>
<td>Apple Inc.</td>
</tr>
<tr>
<td>EvoCam version 3.6.6</td>
<td>Camera interface &amp; optical detector software</td>
<td>$30</td>
<td>Evological Software</td>
</tr>
<tr>
<td>Automator version 2.1</td>
<td>Automation and integration software</td>
<td>Free</td>
<td>Apple Inc.</td>
</tr>
<tr>
<td>Keyboard Maestro 4.1</td>
<td>Data sorting keyboard interface</td>
<td>$36</td>
<td>Stairways Software Pty Ltd.</td>
</tr>
<tr>
<td>Hazel version 2.3.5</td>
<td>Data sorting &amp; tagging software</td>
<td>$21.95</td>
<td>noodlesoft, Inc.</td>
</tr>
<tr>
<td>Bento version 2.0.3</td>
<td>Data analysis and database software</td>
<td>$49</td>
<td>FileMaker, Inc.</td>
</tr>
<tr>
<td>.Mac</td>
<td>Online hosting</td>
<td>$99</td>
<td>Apple, Inc.</td>
</tr>
<tr>
<td>BaseCamp</td>
<td>Project management</td>
<td>$12/mo.</td>
<td>37signals, Inc.</td>
</tr>
<tr>
<td>Screen Flow</td>
<td>Screen recording</td>
<td>$99</td>
<td>Telestream, Inc.</td>
</tr>
</tbody>
</table>
Experimental Conditions

Baseline Condition – Daytime

The daytime baseline condition consisted of a typical roadway environment in the absence of the independent variable (RRFB). Observations during this condition were conducted between sunrise and sunset. Data for the time of sunrise and sunset were automatically gathered from the U.S. Naval Observatory Astronomical Applications Department website at http://aa.usno.navy.mil/. This precise calculator on daytime was used to gain precision around dividing up the observation sessions and to attempt to control some atmospheric variability that could impact the saliency of the independent variable (other atmospheric variables were not controlled for such as smog, rain, snow, fog, or full moons). The main goal in using this strategy was to be able to interpret if motorists were being exposed to the treatment conditions in the presence of more or less ambient light (see Appendix N for a job aid poster describing the baseline condition).

Treatment Condition – Daytime

The daytime treatment condition followed the same sunrise to sunset rules that the daytime baseline condition followed, with the exception of the presence of an active independent variable (RRFB). All other roadway conditions remained unchanged by the researcher (see Appendices R and S for photos of activated RRFB units).

Baseline Condition – Nighttime

The nighttime baseline condition consisted of a typical roadway environment in the absence of the independent variable (RRFB). Observations during this condition were
conducted between sunset and sunrise. Data for the time of sunset and sunrise were automatically gathered from the U.S. Naval Observatory Astronomical Applications Department website.

Treatment Condition – Nighttime

The nighttime treatment condition followed the same sunset to sunrise rules that the nighttime baseline condition followed, with the exception of the presence of an active independent variable (RRFB). All other roadway conditions remained unchanged by the researcher.

Independent Variables

The independent variable consisted of a six-part contextually activated yellow rectangular rapid-flashing beacon (RRFB) system. The first part of the system was a hand-held transmitter that was activated by the emergency vehicle driver during an emergency exit. This transmitter would transmit a signal to a receiver located on the shoulder of the four-lane road across from the center of the fire station’s apron. Once activated, this receiver would then simultaneously activate the RRFBs on two signs that were directed toward north- and southbound traffic, respectively. The signs would emit a high-intensity light. The RRFB beacons flashed with a speed, pattern, and intensity similar to the rapid flashing and bright lights used on emergency vehicles. Each LED flasher is 6 inches wide and 2.5 inches high, and were placed 9 inches apart. In addition, each unit is dual-indicated, with LEDs on the front and back. Each side of the LED flasher illuminates in a wig-wag sequence (left and then right). The left LED flashes two
times in a slow volley each time it is energized (124ms on and 76 ms off per flash). This is followed by the right LED, which flashes four times in a rapid volley when energized (25 ms on and 25 ms off per flash) and then has a longer flash for 200 ms.

The signs were approximately 500 feet from the perpendicular center of the station’s apron. These signs were intended to serve as an early warning to oncoming traffic that an emergency vehicle was approaching. These signs contained two RRFB units that were solar powered and radio activated. The signs were diamond-shaped with a graphic of a black-on-yellow fire engine, and below contained an additional black-on-yellow rectangular sign that read: “WHEN FLASHING.” The signs were instantly activated when the hand-held transmitter was activated.

The final two components of the system were two additional signs, also solar powered and radio controlled, which were placed at the northbound and southbound yield bar markers. These signs each had two RRFB units attached and arrows that pointed to the location of the yield bar. The signs also had a smaller black-on-yellow fire truck image and a sign directly below that read, “DO NOT BLOCK DRIVEWAY.” The RRFB units connected to these signs were activated a few seconds after the more remote signs in order to not alert motorists who had already passed the “WHEN FLASHING” sign. This was done to avoid hard-breaking and allowed motorists to clear the roadway in front of the apron without posing a risk to the exiting emergency vehicles. (See Appendix G for a graphical depiction of the RRFB activation flow and timings. Also see Appendix F for an annotated illustration of the RRFB unit.)
Dependent Variables and Operational Definitions

Vehicle Yielding

The condition of a motorist’s vehicle coming to a complete stop (with no observable forward movement of the vehicle) at or before the yield prompt line during an event of interest (i.e., an emergency vehicle exit in the presence of traffic) (see Appendix P for a job aid poster describing this dependent variable).

Vehicle Failing to Yield

The condition of a motorist’s vehicle failing to come to a complete stop at or before the yield prompt line during an event of interest, and instead penetrating the boundary of the yield prompt line and entering the conflict zone or continuing across the apron.

Yield and Violation Types

Yield before the bar.

The condition of a motorist’s vehicle coming to a complete stop (with no observable forward movement of the vehicle) at least one car-length before the yield prompt line during an event of interest (see Appendix K for a job aid poster describing the yield bar).

At the yield bar.

The condition of a motorist’s vehicle coming to a complete stop (with no observable forward movement of the vehicle) where the front bumper is no more
than one car-length behind the yield bar during an event of interest (see Appendix M for job aid poster that describes an “event of interest”).

Partial Transect Violation

A motorist’s vehicle that partially transects the conflict zone by entering the area directly in front of the station’s apron during an event of interest.

Full Transect Violation

A motorist’s vehicle that completely transects the conflict zone during an event of interest.

Conflict Frequency

The frequency of which a near collision between two motorists or topographical feature on or around the roadway is observed.

Time to Exit

The time in seconds from when the emergency vehicle first becomes visible in the video to the time when the vehicle is perpendicular to the apron (see Appendix O for a job aid poster describing the time to exit dependent variable).
Time of Day

*Daytime.*

Defined based on sunrise to sunset times published by the U.S. Naval Observatory Astronomical Applications Department website at http://aa.usno.navy.mil/.

*Nighttime.*

Defined based on sunset to sunrise times published by the U.S. Naval Observatory Astronomical Applications Department.

See Table 2 for a detailed list and description of all study operational definitions.

Measurement of the Dependent Variables

Observation System Calibration

During the installation of the observation system, the computerized optical detector was calibrated by using a human observer and a series of staged emergency exits. Emergency vehicles would leave one of the three roll up doors and the human observer would verify that the vehicle exit would trigger an event (i.e., the computer would record an event).

During the calibration of the observation system it was observed that other items in the environment could trigger an event. Environmental phenomena such as sunrise (given the cameras eastern exposure) and the reflection of sunlight on broadsided trucks during sunset would regularly trigger an event. Borrowing parlance from statistics, these errors were referred to as Type I errors—the capturing of an event that was not an event of interest. Reducing the sensitivity of the optical detectors to compensate for these errors
Table 2  
*Table of Study Operational Definitions*

<table>
<thead>
<tr>
<th>Term</th>
<th>Operational Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle Yield Line</td>
<td>The location on the street approximately parallel to the to the right and left edges of the apron. Vehicles must yield at or before this line to be considered a “yielding vehicle.”</td>
</tr>
<tr>
<td>Apron</td>
<td>The driveway of the Fires Station indicated by the vertical arrows on the study location map (see appendix A).</td>
</tr>
<tr>
<td>Yield Prompt Line</td>
<td>The location on the apron approximately 50 feet from the edge of the street. Roughly perpendicular to the back of the exit arrows.</td>
</tr>
<tr>
<td>Time to Exit</td>
<td>The time in seconds from when the emergency vehicle first becomes visible in the video to the time when the vehicle is perpendicular to the apron.</td>
</tr>
<tr>
<td>Emergency Exit</td>
<td>An emergency vehicle (identified by the presence of emergency lights flashing) emerges from the station and exits onto the street with emergency lights illuminated &amp; flashing before reaching the Yield Prompt Line.</td>
</tr>
<tr>
<td>Term</td>
<td>Operational Definition</td>
</tr>
<tr>
<td>----------------------</td>
<td>----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Baseline</td>
<td>An emergency vehicle exit that occurs in the presence of traffic with no illumination of the RRFB system (i.e., No lights are visible from any of the RRFBs).</td>
</tr>
<tr>
<td>Treatment</td>
<td>An emergency vehicle exit that occurs in the presence of traffic where the full RRFB system is active and illuminated.</td>
</tr>
<tr>
<td>Event of interest</td>
<td>An <em>emergency exit</em> in the presence of traffic.</td>
</tr>
<tr>
<td>Traffic</td>
<td>Any cars appearing in the northbound or southbound lanes during an observation.</td>
</tr>
<tr>
<td>Conflict</td>
<td>A collision between two motorists or topographical feature on or around the roadway.</td>
</tr>
<tr>
<td>Hard breaking</td>
<td>A fast reduction of speed in speed in which the front portion of the vehicle visibly dips during the breaking event.</td>
</tr>
<tr>
<td>Vehicle Yielding</td>
<td>The condition of a motorist’s vehicle coming to a compete stop (with no observable forward movement of the vehicle) at or before the yield prompt line during an event of interest.</td>
</tr>
<tr>
<td>Term</td>
<td>Operational Definition</td>
</tr>
<tr>
<td>-----------------------------</td>
<td>--------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Vehicles Failing to Yield</td>
<td>The condition of a motorist’s vehicle failing to come to a compete stop at or before the yield prompt line during an event of interest. Instead penetrating the boundary of the yield prompt line and entering the conflict zone or continuing across the apron.</td>
</tr>
<tr>
<td>Does not meet criteria</td>
<td>Any video that does not depict an event of interest</td>
</tr>
<tr>
<td>Conflict Zone</td>
<td>The area directly in front of the station apron defined by the vehicle yield lines on the southbound and northbound lanes</td>
</tr>
<tr>
<td>Yielding Before the Bar</td>
<td>The condition of a motorist’s vehicle coming to a compete stop (with no observable forward movement of the vehicle) at least one car-length before the yield prompt line during an event of interest.</td>
</tr>
<tr>
<td>Term</td>
<td>Operational Definition</td>
</tr>
<tr>
<td>-----------------------</td>
<td>------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Yield at the Bar</td>
<td>The condition of a motorist’s vehicle coming to a complete stop (with no observable forward movement of the vehicle) where the front bumper is no more than one car-length behind the yield prompt line during an event of interest.</td>
</tr>
<tr>
<td>Full-Transect Violation</td>
<td>A motorist’s vehicle that completely transects the conflict zone during an event of interest.</td>
</tr>
<tr>
<td>Partial-Transect Violation</td>
<td>A motorist’s vehicle that partially transects the conflict zone by entering into the area directly in front of the station’s apron during an event of interest.</td>
</tr>
<tr>
<td>Flag for review</td>
<td>Any video requiring a second opinion.</td>
</tr>
<tr>
<td>Nighttime</td>
<td>Defined based on sunset to sunrise times published by NOAA here: <a href="http://www.esrl.noaa.gov/gmd/grad/solcalc/">http://www.esrl.noaa.gov/gmd/grad/solcalc/</a></td>
</tr>
<tr>
<td>Daytime</td>
<td>Defined based on sunrise to sunset times published by NOAA here: <a href="http://www.esrl.noaa.gov/gmd/grad/solcalc/">http://www.esrl.noaa.gov/gmd/grad/solcalc/</a></td>
</tr>
</tbody>
</table>
resulted in unacceptably high instances of Type II errors—events of interest missed by the optical detectors. This was particularly prevalent due to the low contrast between the white painted tops of the emergency vehicles and the white snow that covered the apron during the winter months. Thus it was decided to calibrate the system to have a high rate of Type I errors due to the rarity of events of interest that met all criteria.

Inter-observer Agreement (IOA)

Inter-observer agreement (IOA) was calculated for 22.72% of all observed exits using a random selection based on a random number generator. Observations would, at random, be selected to be included in the IOA assessment so that at least 20% of the observations would be assessed. Agreement ranged from 89 to 100% across all primary dependent variables. Table 3 summarizes the specific mean IOA values across dependent variables.

Table 3

Inter-observer Agreement across Dependent Variables Table

<table>
<thead>
<tr>
<th>Dependent Variable</th>
<th>Percentage Agreement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tx Condition</td>
<td>100%</td>
</tr>
<tr>
<td>Time of Day</td>
<td>99%</td>
</tr>
<tr>
<td>Vehicle Yielding</td>
<td>92%</td>
</tr>
<tr>
<td>Vehicles Failing to Yield</td>
<td>89%</td>
</tr>
<tr>
<td>Time to Exit</td>
<td>94%</td>
</tr>
<tr>
<td>n</td>
<td>100</td>
</tr>
</tbody>
</table>

Note. IOA data were collected on 22.7% of all collected data
Inter-observer agreement was calculated using a percent agreement heuristic as follows: $\text{IOADV} = \left(\frac{\text{Total number of agreements}}{\text{Total number of agreements} + \text{Disagreements}}\right) \times 100$.

Research Assistant Training and Calibration

Research Assistant Training

Research assistants (RA) were selected from psychology undergraduate classes on a volunteer basis. Upon joining the research team, RAs were exposed to a one-hour orientation that provided an overview of the study and the data collection and analysis procedures. During this orientation, RAs were presented with a video that detailed the RA responsibilities and the process. A video was used to assure that new RAs were introduced to the data collection process in the same way as existing and past RAs. After the orientation, RAs were provided access to a simulated data collection environment with a sample database where they were able to engage in the data collection process. Once an RA was able to successfully code 20 videos with 100% accuracy, they were considered “certified” and were then qualified to sort and code data on actual study videos. If an RA did not reach the 20 videos at the 100% standard, they were coached and allowed to repeat the assessment until they reached criteria. No RA required more than two attempts to reach criteria.

During the course of the research project a total of eight undergraduate RAs participated in the data sorting and coding activities. RAs were able to earn incentives for completing data-related tasks. For every 3000 videos coded, RAs were able to choose an individual award (an iTunes® gift card valued at $20). RA’s were also given the
opportunity to forgo the individual award and opt for a group activity if a specified data-related goal (which was agreed upon by all RAs) was reached. Over the course of the study three group activities were conducted and 10 iTunes gift cards were awarded. All activities were pizza dinners held at a local pizzeria (the activities were all funded by the student researcher).

Data Collection Environment

The data collection environment was deliberately set up for the sorting and coding tasks required to evaluate the study dependent variables (DVs). In addition to dedicated computers for each task, research assistants had access to an online scheduling and reporting system that allowed them to schedule data coding and sorting sessions in pairs. Each RA data session was approximately one hour in duration and consisted of each RA spending 15 minutes at each station (e.g., 15 minutes of data sorting, then 15 minutes of data coding). This 15-minute time limit per task was introduced to minimize fatigue and reduced vigilance when conducting the same data-related task over long periods of time. During each data session each RA was able to engage in each data-related task (sorting and coding) twice. A clock and timer were provided in the lab to prompt RAs to change jobs. After two 15-minute sessions, a distinct alarm sounded that prompted the RAs to take a 10-minute break (see Appendix J for a detailed outline of the video coding process).

RAs had easy access to job aids that were posted around their work area. These posters served as job aids and provided visual prompts (both textual and pictorial) on operational definitions, data collection procedures, and computer keys. The posters
provided prompts on the following: video sorting keystrokes, video coding procedure, baseline, treatment, yield prompt line, vehicle yield, vehicle yield line, station exit, time to exit (see Appendices D, and I–N for samples of these posters).

Calibration and Observer Drift

RA’s were calibrated by first coding 20 sample videos with known values for the various DVs. Once the RA was able to code the 20 sample videos at 100% accuracy, they were considered calibrated and then began coding actual study data. One probe for observer drift was conducted by exposing the RA to a random sample of five of the 20 calibration videos to code. This was done three times during the study which resulted in each research assistant being probed for observer drift. If the RA was able to code the five videos with 100% accuracy, they maintained their calibration status and returned to coding study data. If an RA were to fall under the 100% criteria, they would have been re-calibrated by reviewing the operational definitions, the study training materials, and taking the original calibration text again until they reached 100% accuracy. At that point the RA would return to coding study data. During the course of the study no RA scored under the calibration criteria.

HSIRB Approval and Informed Consent

Protocol 11-01-14 was issued clearance from the Human Subjects Institutional Review Board (HSIRB) under exempt status due to the observational nature of the study (see Appendix B). Due to the exempt status and the covert nature of the data collection system, informed consent was not collected.
CHAPTER 3

RESULTS

Average Motorist Yielding during Baseline and Treatment

Daytime and Nighttime Analysis

Daytime and Nighttime Baseline

Figure 1 depicts average motorist yielding during the baseline and treatment conditions across daytime and nighttime sessions. During the baseline condition when motorists were exposed to a typical roadway environment (with no contingently activated RRFBs) legal motorist yielding averaged $M = 18.48$, $SD = 29.78$, 95% CI [13.39, 23.57], during the daytime, and $M = 23.92$, $SD = 38.36$, [18.32, 29.52], during the nighttime. These baseline yielding data were observed over the course of 345 emergency vehicle exits and included observations of 1,009 motorists.

Daytime and Nighttime Treatment

During the treatment conditions when motorists were exposed to the contingently activated RRFB units, legal yielding averaged: $M = 51$, $SD = 41.38$, 95% CI [42.45, 59.54], during the daytime, and $M = 66.07$, $SD = 40.44$, [52.855, 79.29], during the nighttime. These treatment yielding data were observed over the course of 95 emergency vehicle exits and included observations of 234 vehicles/motorists.
Figure 1. Average motorist yielding in baseline (RRFB absent) and treatment (RRFB present) during the daytime and nighttime conditions.

The percentage of motorist’s yielding was calculated as follows: \[
\frac{\text{Total Number of Vehicles Yielding}}{\text{Total Number of Vehicles Not Yielding} + \text{Total Number of Vehicles Yielding}} \times 100.
\]
Percentage of motorists failing to yield was calculated as follows: \[
\frac{\text{Total Number of Vehicles Not Yielding}}{\text{Total Number of Vehicles Not Yielding} + \text{Total Number of Vehicles Yielding}} \times 100.
\]

Daytime: Baseline vs. Treatment T-test

An independent samples t-test was conducted on the daytime session, which compared mean motorist yielding during the baseline condition (absence of the RRFB) with the treatment condition (presence of the RRFB). The test indicated that in the
presence of the RRFB intervention, legal yielding was significantly higher than without the RRFB units, $t(254) = 6.89$, $p < .001$, $d = 0.90$. The observed effect of the RRFB intervention on motorist yielding during the daytime session is large.

Nighttime: Baseline vs. Treatment T-test

Another independent samples t-test was conducted on the nighttime session, which compared mean motorist yielding during the RRFB condition versus the absence of RRFB condition. The test indicated that higher yielding was observed during the RRFB condition, $t(182) p < .001$, $d = 1.07$. Just as in the daytime session, the observed effect of the RRFB intervention on motorist yielding during the nighttime session is large.

Table 4 presents the average motorist yielding data along with the number of observed exits and number of vehicles observed during each exit. The majority of the exits (that met the study's definition of an emergency vehicle exit) were observed during the daytime (256) when compared to exits during the nighttime session (184). An even larger majority favored the daytime sessions when the number of vehicles/motorists are considered: daytime motorists $n = 864$; nighttime motorists $n = 379$. This difference is explained by the natural traffic patterns observed on this road with more traffic observed during the daytime interval versus the nighttime interval.
Table 4

*Average Yielding by Condition and Time of Day*

| Variable        | Daytime | | Nighttime | |
|-----------------|---------|----------------|----------|
|                 | Baseline | Treatment | Baseline | Treatment |
| Average Yielding| 18.48%  | 51%        | 23.92%   | 66.07%    |
| SD              | 29.78   | 41.38      | 38.36    | 40.44     |
| 95% CI          | [13.39, 23.57] | [42.45, 59.54] | [18.32, 29.52] | [52.855, 79.29] |
| n               | 681     | 183        | 328      | 51        |
| Observed Exits  | 189     | 67         | 156      | 28        |

*Note: n = indicates the number of vehicles observed in each condition. CI = Confidence interval*

Overall Analysis

An overall analysis was conducted that aggregated all baseline and treatment data to look for the overall (daytime + nighttime) effectiveness of the intervention and any interaction effects. A 2x2 factorial ANOVA was conducted to evaluate the differences in factor 1: *Condition* - baseline (absence of RRFB) to treatment (presence of RRFB) and factor 2: *Time of Day (TOD)* - daytime and nighttime, along with any potential interaction effects such as the differential effectiveness of the RRFB intervention during the *Time of Day* factor. The *Condition* factor was of primary interest while the *Time of Day* factor was of minor interest given that it could only provide evidence that there is a difference in driver yielding in the presence and absence of the RRFB treatment during the daytime and nighttime. The interaction was of particular interest given its potential to provide evidence that the treatment is more effective during the daytime or nighttime.
The results of the test suggest that significant main effects exist in the *Condition* factor: $F(1,436) = 70.63$, $p < 0.001$, with the treatment condition (presence of the conditional RRFBs), $M = 55.44$, $SD = 41.47$, $95\%$ CI $[50.67, 66.40]$ being significantly higher than the baseline condition (absence of the conditional RRFBs), $M = 20.94$, $SD = 33.99$, $[17.42, 24.98]$.

Significant main effects also exist in the *TOD (Time of Day)* factor: $F (1,436) = 5.33$, $p < 0.05$, which indicates that overall yielding (baseline + treatment) is higher during the nighttime $M = 30.33$, $SD = 41.45$, $95\%$ CI $[37.82, 52.17]$ session when compared to the daytime session, $M =26.99$, $SD = 36.09$, $[29.77, 39.71]$. No statistically significant results were observed in terms of an interaction between the intervention and time of day $F (1,436) = 1.176$, $p > 0.05$. This indicates that the differential effectiveness of the intervention (RRFB condition) observable from the aggregate data does not meet a statistical standard of significance. This last result was somewhat surprising given the initial hypotheses that the saliency of the RRFB light intensity would be greater at night and thus might occasion greater motorist yielding versus the daytime session. Table 5 summarizes these results.

Effect size measures were calculated for the main effect on the factors *Condition* and *TOD* using partial etas. Measures of etas were calculated with the following equation: $\eta^2_{pcons} = \frac{SS_{con}}{SS_{con} + SS_{con}}$. The effect size of the factor *Condition* (presence of RRFB vs. absence of RRFB) resulted in a value of $\eta^2_{pcons} = .139$, which suggests that 13.9% of the between subjects variance is accounted for by the presence of the RRFBs. A much smaller effect was observed in the *Time of Day* factor, $\eta^2_{pcons} = .012$. 

sessions.
Table 5

2x2 Factorial ANOVA: Condition vs. Time of Day

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Condition</td>
<td>89429.78</td>
<td>1</td>
<td>89429.78</td>
<td>70.63</td>
<td>0.000**</td>
</tr>
<tr>
<td>TOD</td>
<td>6752.61</td>
<td>1</td>
<td>6752.61</td>
<td>5.33</td>
<td>0.021*</td>
</tr>
<tr>
<td>Condition*TOD</td>
<td>1488.85</td>
<td>1</td>
<td>1488.85</td>
<td>1.18</td>
<td>0.279</td>
</tr>
<tr>
<td>Error</td>
<td>552044.61</td>
<td>436</td>
<td>1266.16</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>1002319.96</td>
<td>440</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>647719.21</td>
<td>439</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note. ** p < 0.001, *p < 0.05.

Vehicle Yielding and Not Yielding across Time Intervals

Analysis of Yielders across Time Intervals

The evaluation of when motorists who yielded during the no-RRFB and RRFB condition yielded was conducted across specified time intervals during both the daytime and nighttime sessions across the no-RRFB and RRFB conditions to determine if the RRFB intervention affect when vehicles yielded (i.e., earlier vs. later in the exit event). Table 6 summarizes the frequencies of observations in each time interval.
Table 6

Vehicle Yielding by Time Interval: Daytime and Nighttime Sessions

<table>
<thead>
<tr>
<th>Condition</th>
<th>0 - 3s</th>
<th>4 - 7s</th>
<th>8 - 11s</th>
<th>12 - 15s</th>
<th>&gt;15s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Day</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline</td>
<td>15.60%</td>
<td>17</td>
<td>11.01%</td>
<td>12</td>
<td>26</td>
</tr>
<tr>
<td>Treatment</td>
<td>24.10%</td>
<td>20</td>
<td>15.66%</td>
<td>13</td>
<td>16.87%</td>
</tr>
<tr>
<td>n</td>
<td>37</td>
<td>25</td>
<td>52</td>
<td>40</td>
<td>38</td>
</tr>
<tr>
<td>Night</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline</td>
<td>3%</td>
<td>2</td>
<td>5%</td>
<td>3</td>
<td>19</td>
</tr>
<tr>
<td>Treatment</td>
<td>21.43%</td>
<td>6</td>
<td>17.86%</td>
<td>5</td>
<td>14.29%</td>
</tr>
<tr>
<td>n</td>
<td>8</td>
<td>8</td>
<td>26</td>
<td>24</td>
<td>24</td>
</tr>
</tbody>
</table>

Note. n = the frequency of vehicles observed in each time interval.

Cumulative Yielding – Daytime

Figure 2 presents the daytime yielding pattern of all observed yielders (motorists who yielded during the no-RRFB and RRFB conditions) in a cumulative percentage graph during the both conditions. The graph suggests that the RRFB is more effective than no-RRFB in evoking early yielding behavior when baseline is compared to the RRFB treatment during the daytime, between zero and seven seconds into the exit event. During the RRFB condition, on average 40% of motorists yielded between four and seven seconds into the exit event. During the baseline (no-RRFB) condition, only 27% yielded within that time interval. The RRFB advantage in occasioning earlier yielding in compliant yielders largely disappears by the eight-second to 11s interval.
Cumulative Percentage of Vehicles Yielding by Time Interval - Daytime

Figure 2. Cumulative yielding by time interval of motorists who yield regardless of condition, during the daytime session; baseline (absence of RRFB) and treatment (RRFB) conditions.

Cumulative Yielding – Nighttime

Figure 3 presents the nighttime yielding pattern in a cumulative percentage graph during the no-RRFB and RRFB conditions. The graph suggests that the RRFB was significantly more effective than the no-RRFB condition at increasing early yielding behavior of those motorists who yielded between zero and 15s, with the interval of zero to 11s into the exit event with the largest deviation from the no-RRFB line in the
direction of earlier yielding. Between eight and 11s into the exit event, the RRFB condition, on average prompts approximately 64% of motorists to yield earlier than their counterparts, the no-RRFB condition, where only 39% of yielders yield by that time interval. In the nighttime condition, the RRFB advantage in occasioning earlier yielding in compliant yielders maintains beyond the 15s interval.

Figure 3. Cumulative yielding by time interval of motorists who yield regardless of condition, during the nighttime session; baseline (absence of RRFB) and treatment (RRFB) conditions.
Analysis of Non-yielders across Time Intervals during the Daytime and Nighttime Sessions

The following analysis investigated the extent to which the RRFB would change time of violation for those motorists who failed to yield during the no-RRFB and RRFB conditions. Table 7 summarizes the frequencies of observed non-yielders in each time interval.

Table 7

*Vehicles Not Yielding by Time Intervals: Daytime and Nighttime*

<table>
<thead>
<tr>
<th>Condition</th>
<th>0 - 3s</th>
<th>4 - 7s</th>
<th>8 - 11s</th>
<th>12 - 15s</th>
<th>&gt;15s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>%</td>
<td>f</td>
<td>%</td>
<td>f</td>
<td>%</td>
</tr>
<tr>
<td></td>
<td>27.90%</td>
<td>279</td>
<td>35.80%</td>
<td>358</td>
<td>22.10%</td>
</tr>
<tr>
<td>Treatment</td>
<td>39.48%</td>
<td>92</td>
<td>30.04%</td>
<td>70</td>
<td>21.03%</td>
</tr>
</tbody>
</table>

| n | 371 | 428 | 270 | 100 | 64 |

<table>
<thead>
<tr>
<th>Night</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
</tr>
<tr>
<td>Treatment</td>
</tr>
</tbody>
</table>

| n | 128 | 141 | 109 | 52 | 85 |

Note. n = the frequency of non-yielding vehicles observed in each time interval.

Daytime Analysis of Non-yielders

Figure 4 depicts the pattern of non-yielders across specified time intervals. The daytime pattern indicated that the RRFB condition resulted in slightly earlier violations.
when compared to the no-RRFB condition. The most significant difference can be observed between zero and three seconds where 39.48% of violators failed to yield compared to 28% during the no-RRFB condition. After that interval the RRFB condition still occasions slightly earlier violations until the greater than 15s interval.

Figure 4. Cumulative non-yielding by time interval during the daytime session; baseline (absence of RRFB) and treatment (RRFB) conditions.

Nighttime Analysis of Non-yielders

Figure 5 depicts the pattern of non-yielders across specified time intervals. This nighttime pattern does not look very differentiated when comparing violations across
intervals during the no-RRFB and RRFB conditions. The only separation exists during the 12 to 15s interval where it was observed that the RRFB condition occasioned 86% failure to yield up to that interval while the no-RRFB condition yielded 94% failure to yield.

Figure 5. Cumulative non-yielding by time interval during the nighttime session; baseline (absence of RRFB) and treatment (RRFB) conditions.
Yield and Violation Type Analysis

The following analysis was conducted to investigate how yield types and violation types changed during the no-RRFB and RRFB treatment conditions across daytime and nighttime sessions. Table 8 provides additional detail on the frequency of vehicles observed in each yield and violation type.

Table 8

*Vehicle Yielding and Violation Type Frequencies and Percentages*

<table>
<thead>
<tr>
<th>Condition</th>
<th>Yielding before yield</th>
<th>Yielding at yield</th>
<th>Partial transect</th>
<th>Full-transect</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>%</td>
<td>f</td>
<td>%</td>
<td>f</td>
</tr>
<tr>
<td>Daytime</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline</td>
<td>5.87%</td>
<td>39</td>
<td>10.69%</td>
<td>71</td>
</tr>
<tr>
<td>Treatment</td>
<td>16.57%</td>
<td>30</td>
<td>29.83%</td>
<td>54</td>
</tr>
<tr>
<td>n</td>
<td>69</td>
<td>125</td>
<td>100</td>
<td>551</td>
</tr>
<tr>
<td>Nighttime</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline</td>
<td>9.03%</td>
<td>29</td>
<td>9.35%</td>
<td>30</td>
</tr>
<tr>
<td>Treatment</td>
<td>23.53%</td>
<td>12</td>
<td>37.25%</td>
<td>19</td>
</tr>
<tr>
<td>n</td>
<td>41</td>
<td>49</td>
<td>50</td>
<td>232</td>
</tr>
</tbody>
</table>

Note: n = Number of cars observed in each yielding and violation category during daytime and nighttime sessions across no-RRFB and RRFB conditions.

Daytime Yield and Violation Type Analysis

Figure 6 presents no-RRFB and RRFB data from the daytime session. During the daytime session full transect violations during the baseline condition were the most...
common observation across all observation sessions moved from M = 71.54, to M = 41.99 during treatment. Partial-transect violations remained largely unchanged from no-RRFB to the RRFB condition M ≈ 12. Yielding at the yield bar increased nearly three times from M = 10.69 during the no-RRFB condition to M = 29.83 during the RRFB condition. Yielding before the bar increased from M = 5.87 during the no-RRFB condition to M = 16.57 during the RRFB condition.

Figure 6. Profile of yield and violation types during the daytime condition across no-RRFB and RRFB conditions.
Nighttime Yield and Violation Type Analysis

Figure 7 presents no-RRFB and RRFB data from the nighttime session. During the nighttime session full transect violations during the baseline condition were the most common observation across all observation sessions moved from $M = 67.91$, to $M = 27.45$ during treatment. Partial-transect violations decreased slightly from $M = 13.71$ during the no-RRFB to $M = 11.76$ during the RRFB condition. Yielding at the yield bar increased well over three times—nearly four—from $M = 9.35$ during the no-RRFB condition to $M = 37.25$ during the RRFB condition. Yielding before the bar more than doubled from $M = 9.03$ during the no-RRFB condition to $M = 23.53$ during the RRFB condition.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure7.png}
\caption{Profile of yield and violation types during the nighttime condition across no-RRFB and RRFB conditions.}
\end{figure}
Time to Exit Analysis

An analysis of the duration of emergency vehicle exit was conducted to see if the RRFB intervention had any significant influence on the time required for the emergency vehicle to exit the station's apron and enter the roadway. Figure 8 presents a graphical representation of the observed data of the time to exit for both daytime and nighttime sessions, across both no-RRFB and RRFB conditions. A more detailed summary of these data is available in Table 9. The differences in exit times are not practically different between the daytime no-RRFB baseline, M = 17.54, SD = 5.32, and RRFB conditions M = 17.72, SD = 6.16, and nighttime no-RRFB baseline, M = 20.54, SD = 9.34, and RRFB conditions M = 21.71, SD = 10.85.

**Figure 8. Mean time in seconds for an emergency vehicle to exit the station’s apron and merge onto the roadway during daytime and nighttime sessions, across no-RRFB and RRFB conditions.**
Table 9

Time to Exit in Seconds

<table>
<thead>
<tr>
<th></th>
<th>AM Baseline</th>
<th>AM Treatment</th>
<th>PM Baseline</th>
<th>PM Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time to exit</td>
<td>17.53</td>
<td>17.72</td>
<td>20.54</td>
<td>21.71</td>
</tr>
<tr>
<td>SD</td>
<td>5.32</td>
<td>6.16</td>
<td>9.34</td>
<td>10.85</td>
</tr>
<tr>
<td>n</td>
<td>189</td>
<td>67</td>
<td>156</td>
<td>28</td>
</tr>
</tbody>
</table>

Note: n - indicates the number of vehicles observed in each condition.

The results of a 2x2 Factorial ANOVA run to evaluate treatment condition on time to exit, and time of day on time to exit, yielded insignificant results in the treatment factor. F(1, 436) = 0.53, p > .05 and the interaction of treatment by time of day, F(1,436) = 0.27, p > .05. However there was a significant difference when the baseline + treatment conditions for the daytime and nighttime sessions were compared to each other. The Time of Day (TOD) factor yielded significant results, F (1,436) = 14.04, p < .001, \( \eta^2_{\text{partial}} = .031 \) which indicates the 3.1% of the variability in time to exit is due the time of day.

With daytime exits, M = 17.62, SD = 0.53, 95% CI [16.58, 18.67] being significantly shorter than nighttime exits, M = 21.13, SD = 0.77, [19.62, 22.64].

Conflict Frequency Analysis

Data were collected on the frequency of observed conflicts (near collisions) during all sessions and conditions. Table 10 summarizes these observations. The total number of observed conflicts was eight, when this frequency is corrected for exposure,
by dividing the total number of conflicts by the total number of observed vehicles by condition/session, rate of exposure which provides a more meaningful view of the data. The rate of observed exposure during the daytime baseline and treatment conditions are 0.88% and 0.55% respectively. During the nighttime session, only one conflict was observed during the baseline condition, which resulted in a conflict exposure rate of 0.30%. Due to the small number of observed conflicts, these data are just presented for informational purposes. Any valid inference would require a much larger sample size.

Table 10

*Vehicle Conflict Frequency*

<table>
<thead>
<tr>
<th>Condition</th>
<th>Conflicts</th>
<th>Vehicles Observed</th>
<th>Corrected Conflict Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Day</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline</td>
<td>6</td>
<td>681</td>
<td>0.88%</td>
</tr>
<tr>
<td>Treatment</td>
<td>1</td>
<td>183</td>
<td>0.55%</td>
</tr>
<tr>
<td>Total</td>
<td>7</td>
<td>864</td>
<td></td>
</tr>
<tr>
<td><strong>Night</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline</td>
<td>1</td>
<td>328</td>
<td>0.30%</td>
</tr>
<tr>
<td>Treatment</td>
<td>0</td>
<td>51</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>1</td>
<td>379</td>
<td></td>
</tr>
</tbody>
</table>

*Note. Conflict data corrected for exposure using the formula: corrected conflicts = observed conflicts / total observed vehicles for the given condition*
CHAPTER 4
DISCUSSION

Based on the data collected in the present study, it appears the RRFB-enhanced yield signs coupled with the timing functions might be effective in increasing the frequency of motorist yielding to exiting emergency vehicles. When the daytime data are considered, the baseline yielding is increased over 2.7 times when compared to the data collected during the daytime intervention phase (18% to 51%). A similar pattern is seen when the nighttime data are considered. An increase of average yielding of over 2.7 times is observed when the nighttime baseline yielding is compared to the nighttime treatment data. Both the daytime baseline versus treatment and nighttime baseline versus treatment data displayed in Figure 1 exhibit a similar pattern and both increases also represent a statistically significant difference with large effect sizes (daytime: t(254) = 6.89, p < .001, d = 0.90; nighttime: t(182) p < .001, d = 1.07). While one must cautiously infer causality due to the AB nature of the study, the fact that the patterns of data are quite similar during the daytime and nighttime conditions lends support to the validity of these results.

Before conducting the study it was hypothesized that RRFB would be more effective at prompting driver yielding at night due to the enhanced saliency of the RRFB in the absence of competing light sources. This hypothesis was not supported by the data. The RRFB was not shown to be differentially effective across different levels of Time of Day factor, F (1,436) = 1.176, p > 0.05. While the difference in effect on average motorist yielding between baseline and treatment seem apparent in favor the nighttime
versus the daytime sessions \( \Delta_{\text{daytime}} = 33\% \) vs. \( \Delta_{\text{nighttime}} = 42 \), the high variability in the samples led to increased statistical error, which suggests that this difference is due more to random chance than the systematic effects of the RRFB intervention.

Once the effectiveness of the RRFB intervention was demonstrated during both the daytime and nighttime sessions, the question of how the RRFB intervention was affecting yielders and non-yielders at different time intervals across the exit event was analyzed. The cumulative yielding data for daytime yielders summarized in Figure 2 and Table 6 indicate the RRFB intervention has a positive impact on yielders between zero and seven seconds into the exit event. During this time the RRFB intervention appears to occasion earlier yielding when compared to baseline conditions in the daytime. This effect is largely gone after eight to 11s into the exit event. An even greater effect is viable during the nighttime sessions where the RRFB seems to maintain its effectiveness at occasioning earlier yielding when compared to baseline up to 11s into the exit event.

A similar analysis was conducted to investigate how the RRFB intervention might affect non-yielders in both treatment and baseline conditions (these data are summarized in Figure 4 and Table 7). During the daytime sessions it was observed the RRFB condition may have occasioned slightly earlier violations when compared to the baseline motorist’s failing to yield. By the eight to 11s interval, 90% of all non-yielders had violated during the RRFB condition compared to 86% violating by the same interval in the baseline condition. Perhaps in the case of earlier violation, the RRFB is providing a discriminative stimulus to drivers prompting an acceleration response. No meaningful difference between RRFB and baseline conditions were viewed in non-yielders during the nighttime sessions with the exception of a small reduction in non-yielders failing to
yield during the RRFB condition in the 12 to 15s interval during the daytime session. Other than that, the pattern appears to be identical between the baseline and treatment data.

Yield and Violation Types

An analysis was also conducted to investigate how the topography of yielding and failure to yield were impacted by the RRFB intervention when RRFB and baseline conditions were compared (these data are summarized in Figures 6 and 7 with additional details in Table 8). Motorists were evaluated based on the type of violation they made (i.e., full-transect or partial transect) and the type of yield they made (i.e., at the yield bar or before the yield bar).

Before the study was conducted, it was hypothesized that the RRFB might occasion yielding at a large distance before the yield bar instead of at the yield bar. This early yielding behavior has been seen in studies using the RRFB-based intervention to increase yielding to pedestrians in pedestrian crosswalks (see Shurbutt et al., 2009). When analyzing yielding before the bar in the daytime and nighttime conditions, it was found that there is evidence that this effect is also present when using an RRFB intervention with respect to yielding to exiting emergency vehicles. In the daytime conditions yielding before the bar increased over 2.8 times (baseline M = 5.87, RRFB M = 16.57). This pattern is even more pronounced in the nighttime data where yielding before the bar increased over 2.6 times during the RRFB treatment when compared to the baseline condition (baseline M = 9.03, RRFB M = 23.53). These data suggest that the RRFB may be effective at increasing the distance from the yield bar of yielding
motorists. Yielding at the yield bar also increased significantly by over 2.7 times when the baseline yielding at the yield bar is compared to the RRFB condition.

When analyzing the types of violations the data suggest that the RRFB is effective at significantly reducing the percentage of motorists who are engaging in full-transect violations (which can be the most dangerous given the speed and momentum of the vehicles as they transect the area in front of the station’s apron). Baseline levels of full-transect violations decreased from 72% to 42% during the daytime RRFB intervention. Thus it appears as if the RRFB is effective at not only decreasing the total number of non-yielders but also reducing the proportion of non-yielders that engage in full-transect violations.

Curiously the data indicate that partial-transect violations were unchanged by the RRFB intervention during the daytime, remaining at a nearly consistent level when baseline levels of partial-transect violations were compared to treatment levels (baseline \( M = 11.9 \), treatment \( M = 11.6 \)).

The nighttime analysis of yield type and violation analysis followed similar patterns as the daytime data with a few exceptions. A much larger decrease in the proportion of full-transect violators was observed during the nighttime sessions when baseline levels are compared to RRFB levels (baseline \( M = 67.91 \), treatment \( M = 27.45 \)). This suggests that the RRFB might be particularly effective at reducing the most dangerous type of violation at night. This could be due to the enhanced saliency of the RRFB during the nighttime when fewer competing light sources are present. This could also be due to the fact that at night, the RRFB is perceptible far earlier than during the daytime when greater ambient light is in the environment.
It should also be noted that during the nighttime sessions partial-transect violations decrease slightly when baseline data are compared to RRFB data in contrast to the daytime sessions (baseline $M = 13.71$, treatment $= 11.76$).

Time to Exit

An initial hypothesis of the study was that the RRFB may be effective in reducing speed to exit, thus having an impact on how quickly emergency vehicles were able to arrive on scene. This was not supported by the data. Figure 8 illustrates the time to exit data during daytime and nighttime sessions across baseline and RRFB conditions. Time to exit data remains stable across sessions and is only slightly different when comparing baseline and RRFB data during the nighttime sessions however these differences are not significant and likely due to chance. One significant result that does exist is that when baseline and treatment data are aggregated during daytime and nighttime respectively and then compared, there does appear to be a significant difference in the time to exit with nighttime exits, $F(1,436) = 14.04, p < .001, \eta^2_{partial} = .031$. While this difference cannot be explained by the treatment, it could be heightened caution of emergency vehicle drivers due to the reduced visibility at night might slightly but significantly, increase times to exit. However, it is important to note that these small difference are most likely not clinically significant in terms of patient outcomes.
Behavioral Chain of the Yielding Response
and Theoretical Mechanism of Action

In discussing the effectiveness of the RRFB as a yielding prompting device it might be helpful to compare the theoretical behavioral chains in the presence and absence of the RRFB intervention. A proposed theoretical account of the mechanism of action is presented below.

When yielding in the presence of the RRFB device, the first step in the chain appears to be an orienting response elicited by the flashing light pattern of the RRFB. This orienting response brings the sign prompt into the motorist’s visual field and the sign seems to serve as a discriminative stimulus for an avoidance response (avoiding probable penalty-contingencies or possible conflicts) based on a rule-based learning history of complying with traffic signs and their correlation to actual hazards on the roadway or probability of a penalty. Along with the orienting response and rule-based contingency, a reduction of speed seems to immediately follow the orienting response where the motorist engages the speed reduction control operand (brake pedal). This speed reduction could be both a respondent- and operant-controlled conditioned based on a history of past speed reductions in the presence of novel roadway conditions.

The following is a theorized behavioral view of conditions that are associated with increased probability of yielding. The first is motorist speed. The faster the motorist is traveling the less likely the motorist will yield when prompted. Fast moving motorists are more likely to commit full transect violations and continue in their direction of travel. Another predictor of compliant yielding is the distance to yield point. In general, the longer the distance the motorist has to yield, the more likely they will in fact engage in a legal yield. Time is also a predictive variable. The less time the motorist has to engage in
the yielding response the less likely the motorist will in fact yield. Another key environmental factor could be the presence of value-altering environmental stimuli that can also affect the likelihood of a safe and legal yield. The presence of a police car or law enforcement officer will also temporarily change the value of multiple environmental stimuli (provided that the officer is not visibly distracted or actively involved in ticketing another motorist) and increase the probability of motorist yielding. These factors all seem to interact in an interrelated manner that either improve or reduce the probability of a safe and legal yield.

Behavioral Profiles of High and Low Probability Yields

The profile of an environment which would occasion the highest likelihood of motorist yielding might look as follows: A lower motorist speed with an early and salient yield prompt (that has a high correlation of being associated with an event requiring a yield) that allows sufficient distance to a clearly visible yield location with the yield prompt allowing for sufficient time for the motorist to reduce their speed of travel to a full rest without engaging in hard breaking. This profile can be further enhanced if other vehicles in the motorist’s immediate environment are also yielding and, even further, if a law enforcement presence is visible in the immediate environment and is not visibly occupied or distracted.

The profile of an environment where yielding is improbable: A high-speed road where motorists routinely exceed the speed limit where fixed non-contingent signs don’t have a high correlation between the signaling stimulus and an event requiring a yield. Where the actual stimuli to yield (e.g., emergency vehicle lights or sirens) occur too
temporally proximal to the required behavior with little distance in which to engage in the yielding response. The probability of yielding can be further reduced if other motorists on the road are also failing to yield (i.e., platooning). Another proposed variable that could be key in the response chain of not yielding are any motivating variables that might be affecting the motorist moment-to-moment. A motorist experiencing a condition of time urgency (mediated by rules and enhanced by previous learning history) may be more likely to speed and not comply with traffic-related rules and environmental contingencies related to yielding.

**Strengths of the RRFB Intervention**

A particular strength of the RRFB intervention is that it modifies the environment to better match the profile of an environment where yielding is more theoretically probable. One of the most powerful components of the RRFB intervention seems to be the saliency and conspicuousness of the RRFB to occasion the orienting stimulus that is accompanied by a concomitant speed reduction. This speed reduction results in the motorist having more time and distance in which to engage in the yielding response.

Another strength is that due to the contextual nature of the RRFB’s activation over time, motorists will learn the contingencies associated with the RRFB activation and thus, the use of the device may actually occasion greater yielding compliance over time. This is distinctly different than non-contextually activated signs which, as time goes on, have a deduction in their prompting strength due to a low correlation between their ability to prompt a response and the need for a motorist to engage in the prompted response such as in yielding. The assertion that the RRFB intervention might not diminish over time is
supported by a study conducted by Shurbutt et al. (2009). In this study, RRFB units were attached to pedestrian yielding signs in an effort to assess the RRFB’s utility in increasing motorist yielding to pedestrians in a crosswalk. It was found that not only was the RRFB treatment effective in significantly increasing the frequency of motorists yielding to pedestrians, it was also suggested that the one-to-one correspondence between RRFB activation and the presence of a pedestrian was responsible for the effect.

When considering how the RRFB is able to occasion the orienting response and the related chain of responses, VanWagner (in press) describes the following analysis of the RRFB as an unconditioned stimulus as it related to speed limit signs:

RRFB functions as an unconditioned stimulus (US) which elicits an orienting response that ultimately causes the driver to come in contact with the speed limit sign, an antecedent stimulus, which, it will be argued functions as both a discriminative stimulus and motivating operation to evoke a chain of behavior resulting in improved compliance with the posted limit. Second, due to the many stimulus attributes that it shares with the lights used on emergency vehicles, it is possible that in addition to functioning as a US, the RRFB may also function as an established conditioned motivating operation (CMO) whose motivating properties come from pairing with the bright lights commonly seen on police vehicles, which in turn have, for many drivers been paired with aversive consequences or threat of aversive consequences. As a result, contingent onset of the beacon in the presence of the speed limit may function create an aversive condition which can be escaped by reducing speeds (pg. 26 – 27).
Given the similarities between the application of an RRFB-based intervention on speed control and the current study, one might cautiously suggest that the preceding analysis may also be valid in explaining how the RRFB intervention may work based on a respondent analysis. The orienting stimulus effect of the RRFB is a necessary, but not sufficient, condition to occasion the behavioral chain that results in a safe and legal yielding response. The discriminative function of the sign (as a conditioned establishing operation) may occasion interlocking rule-based contingencies that interact with current person variables such as motivation and environmental variables like those described in the high-probability and low-probability yield profiles, which all serve critical and interactive roles in controlling a motorist’s yielding response.

Strengths of the Study

Two major strengths of the present study were the length of the analysis and the inconspicuous data collection system. The student investigator collected data from 12/15/2007 to 7/10/09. This lengthy analysis allowed for sufficient data collection for the present analysis and to capture repeated examples of cases where emergency vehicles exited with and without the RRFB intervention. It also allowed for the collection of a significant amount of baseline data so that trends and yielding variability could be evaluated before the treatment (n = 123) was introduced.

The covert nature of the data collection system also limited reactivity that could be created by human observers or more conspicuous data collection measures. Related to this strength is the automated nature of the data collection system. The fact that emergency vehicle exits that matched the study requirements for inclusion were so rare,
an automated system and a long analysis represented one of the only practical approaches
to gaining the data necessary for this analysis.

Limitations

A major limitation of the study was in the research design and a relatively low
number of observations in each condition for statistical analysis. AB studies have a
limited ability to demonstrate causal relations, however when repeated and similar
patterns in data emerge, confidence in the data collected increases. While the data
collected were sufficient for the analyses used, larger sample sizes would increase
statistical power and enhance the confidence in the results.

The original intent of the study was to conduct a multiple baseline with an ABAB
reversal across daytime and nighttime sessions, however this was not possible. The main
issue that occasioned the change in research designs was the difficulty in getting
sufficient data at the required times. This was largely due to the strict criteria for an
emergency exit to be included in a reasonable amount of time. In a given week a single
emergency vehicle exit that met the criteria for inclusion in the treatment condition might
only occur between zero and five times. In some months, no qualifying observations were
made over several weeks. The irregular nature of emergency vehicle exits, the dynamic
shifts in traffic patterns, and the ethical, safety, and validity issues involved with
simulating an emergency event made the collection of data in the originally planned
design impractical. The present study conducted data collection over three years. To gain
sufficient data in the pattern prescribed by a multiple baseline across sessions with an
ABAB reversal could have doubled or tripled the data collection time period. The
solution the student investigator chose was to aggregate all daytime and nighttime data across baseline and intervention conditions to use a statistical analysis instead of a time-series design with visual analysis. Overall, the theses weaknesses illustrate the challenges in researching low frequency events particularly in applied environments.

Another limitation making a return to baseline difficult was in working with the emergency responders themselves. Anecdotally they perceived the RRFB system to be highly effective and were not open to discontinuing its use despite requests and conversations regarding research design. When the system was not in use or not functioning, users would actively seek a resolution to reengage the system. These culture issues made a reversal of the RRFB intervention very difficult for more than a few weeks at a time. Fortunately, these short reversals throughout the year allowed for sufficient data to be collected in each of the four conditions (i.e., daytime-baseline, daytime-treatment, nighttime-baseline, and nighttime-treatment).

A final limitation was in how the data were collected on yielders and non-yielders. In an effort to take as conservative measures as possible, all non-yielding motorist’s were counted, however this created a disproportionate measure. In any given observation session there could only be a maximum of 4 yielders, two in each lane in the northbound direction and two in each lane of the southbound direction. Motorists who yielded behind other motorists were said to have been “forced to yield” due to the fact that the only other option was to collide with the vehicle in front of them. These “forced yielders” were not considered due to the fact that it was unlikely that the presence or absence of the RRFB device was controlling the motorist’s behavior. Future studies
might consider how to address this issue in a more equitable manner without relying on such a conservative approach.

Recommendations for Future Research

Future research in this area might consider focusing on the use of RRFB-enhanced signs in more frequent traffic-related events such as: slowing at curves, yielding for trains, not turning when pedestrians are in the crosswalk at traffic signals and in road construction zones.

Future studies might also seek out ways to use more powerful research designs that would add to the body of research on the utility of the RRDB in enhancing the effectiveness of traffic signs on controlling motorist behavior and increasing the safety of all those on and around motorways.

Conclusion

The risks that exist for emergency responders and motorists in close proximity to responding emergency vehicles still exist. Ameliorative strategies are needed now more than ever as the injury and fatality data suggest that the problem is getting worse. We have reached the practical limits of making sirens louder and flashing lights brighter. It appears the environmental modifications of the motorist’s environment with the use of contingently activated signs outfitted with RRFB units could provide real solutions to make roadways safer for emergency responders and motorists alike. While more studies are necessary before we can make firm conclusions, it does appear that this is a fruitful area of inquiry.
REFERENCES


influence the risk of being passively involved in a collision? *Epidemiology, 13*(6), 721-724.


Appendix A

Annotated Map of Research Location
Study Research site: 1300 S. Lake St. Mundelein, IL 60060
Appendix B

HSIRB Approval Letter
Date: December 5, 2007

To: Ron Van Houten, Principal Investigator
   Michelle VanWagner, Student Investigator
   Erick Marinajno, Student Investigator

From: Amy Naugle, Ph.D., Chair

Re: HSIRB Project Number: 07-16-C3

This letter will serve as confirmation that your research project entitled “Assessment of the Effects of a Rapidly Flashing Stutter Beacon on Drivers Yielding the Right of Way to Emergency Vehicles Exiting Fire Stations” has been approved under the exempt category of review by the Human Subjects Institutional Review Board. The conditions and duration of this approval are specified in the Policies of Western Michigan University. You may now begin to implement the research as described in the application.

Please note that you may only conduct this research exactly in the form it was approved. You must seek specific board approval for any changes in this project. You must also seek reapproval if the project extends beyond the termination date noted below. In addition, if there are any unanticipated adverse reactions or unanticipated events associated with the conduct of this research, you should immediately suspend the project and contact the Chair of the HSIRB for consultation.

The Board wishes you success in the pursuit of your research goals.

Approval Termination: December 5, 2008
Appendix C

Flowchart of the Observation and Data Processing Process
Appendix D

Screenshot of the Data Collection Database
Appendix E

Data Categorization Coding Prompts Poster
Video Coding Key

F13

F16
Appendix F

Detailed Illustration of RRFB Enhanced Yielding Signs
Antenna
Solar panel 16.5" x 19.75" (size varies by latitude and uses)
16.5" x 19.75" (size varies by latitude and uses),
LEO Sign Lights
128"
High Intensity Reflective Sheeting on Signs
Custom Designed Aluminum Housing 26" x 4" x 4"
Verification Light
(on back)
LED Lights
85.5" 84" 88"
72"
Appendix G

Flowchart of RRFB Activation Chain and Timing
RRFB activation flow with delays and activation durations. Once activated the RRFB is in operation for a total of 1min 8s.
Appendix I

Still Frames of the Optical Detectors Video Output
Appendix J

Video Coding Procedure Poster
**Video Coding Procedure**

1 Log on & Set Up Procedure
   - 1.1 Log on to the computer.
   - 1.2 Log into the project site & post your starting video title.
   - 1.3 Open the folder "Mundelein, IL - Exit Data site."

2 Video Database Input Procedure
   - 2.1 Open the Database.
   - 2.2 Match the file name in the database to it's corresponding file in the "Mundelein, IL - Exit Data site" folder.
   - 2.3 Drag the video file from the folder into the video section of the database.

2.4 Once the video file appears in the database:
   - Return to the Mundelein, IL - Exit Data site.
   - Highlight the video file you just moved to the database.
   - Click button "TH" - This will turn the file blue.
   - After a short period of time the file will disappear from the Mundelein, IL - Exit Data site.

3 Video Coding Procedure
   - 3.1 Position in the database.
   - 3.2 Highlight either the beginning play or moving the thumbnail bar.
   - 3.3 Enter the project code with a gray highlighted.
   - 3.4 Refer to the operation schedule for information on firing in the database.

3.5 Underneath the thumbnails and video or if there are individuals about a video enter a status code of "A" and the number of the student.

3.6 Find the video you have coded.

3.7 Mark the code B - 15 until done.

4 Closing procedure
   - 4.1 Leave any comments you might have on the project site along with a general number of videos you coded and which video you last coded.
   - 4.2 Click on the link in the upper right hand corner of the section and exit from screen.
   - 4.3 Make sure the exit door is locked when you leave.
   - 4.4 Leave knowing how much I appreciate your individual efforts on this project.
Appendix K

Vehicle Yield Line Poster
Appendix L

Yield Prompt Line Poster
Yield Prompt Line

The location on the apron approximately 50 feet from the edge of the street. Roughly perpendicular to the back of the exit arrows.
Appendix M

Station Exit Poster
Emergency Exit

An emergency vehicle (identified by the presence of emergency lights) emerges from the station and exits onto the street with emergency lights illuminated & flashing before reaching the Yield Prompt Line.
Appendix N

Baseline Poster
Baseline

A Station Exit occurs with no illumination of the alert system (i.e., No lights are visible from any of the three alert posts).
Appendix O

Time to Exit Poster
Time to Exit
Appendix P

Vehicle Yield Poster
Vehicle Yield

In the event of a station exit, vehicles must come to a stop (or near stop - moving no faster than idle speed) at or behind the Vehicle Yield Line when the emergency vehicle's front tires reach the Yield Prompt Line.
Appendix Q

Treatment Poster
Treatment 1
Appendix R

Photo of Activated RRFB Attached to Black-on-Yellow Fire Truck Sign
The secondary RRFB unit can be seen in the lower right-hand corner of this photo.
Appendix S

Photo of Activated RRFB with Yield Prompt Arrow