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Performance Analysis of Squad Car Lighting, Retro-reflective Markings, and Paint Treatments to Improve Safety at Roadside Traffic Stops

Final Report

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16. Abstract (Limit: 250 words)

In the United States, more police officers are killed in collisions at roadside stops than through felonious acts. Causal factors that affect police safety at roadside stops include officer conspicuity, squad conspicuity, weather conditions, and the attention and fatigue level of the traveling public.

Described herein is a research project that provides insight and guidelines that may ultimately improve officer safety at roadside stops. The project is designed to modify an existing sensor-based traffic monitoring system so that it serves as a test bed to evaluate the retro-reflector, lighting, and paint treatments of an emergency vehicle to determine whether particular combinations produce improved “move over” behavior of oncoming traffic. This is done using automated data analysis software built specifically for this project. Tests are performed at a fully instrumented rural intersection. After mimicking a traffic stop where a patrol vehicle is placed at this intersection, the experimenter logs onto a website and enters the time when the test took place. Analysis software draws results from the data. The results are e-mailed to the experimenters, who devise their own test regimes, following the guidelines presented herein, and draw their own conclusions.

A second system was built to provide a more portable option for testing in urban areas. This system consists of two freestanding radar boxes with wireless communication, as well as one netbook computer. Test procedures and results are analogous to the original system. Additional calibration is automatically performed to account for the variable position of the radars.

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Executive Summary

More U.S. police officers are killed in collisions at roadside stops than are killed through felonious acts. According to the International Association of Chiefs of Police, roadside crashes killed 120 police officers from 1995 to 2004, an average of one officer every month.

Conspicuity of a squad car plays an important role in roadside safety. However, the level of conspicuity of a certain treatment of an emergency vehicle is not easily quantifiable. The purpose of this project was to determine a simple performance measure to quantify squad car conspicuity and to develop a simple testing strategy to collect and evaluate data pertaining to the performance measure.

The performance measure selected is based on the “Ted Foss” move-over law, Minnesota State statute 169.18, subd. 11. This law requires that as motorists pass a stationary emergency vehicle, they must attempt to leave a vacant lane between their vehicle and the stationary emergency vehicle, or significantly reduce their speed. The approach described herein uses radar sensors located along an expressway to measure the response of traffic to various emergency vehicle lighting and other treatments. Because modern radar provides range, speed, and azimuth angle to target information for each detected target, the speed and lane positions of traffic passing the scene of a mock traffic stop are detected by these radar sensors positioned along the highway.

Custom, web-based software has been written to collect, analyze, and present the results of a test. The test results are presented in graphical form and are emailed to the testing personnel. In the event of like-conditions between tests involving different vehicle treatment schemes, the schemes can be compared objectively. The more ideal the merging behavior of the passing traffic, the more conspicuous the scheme.

For the portable system, the processing and analysis are done on site via the connect computer. Results are immediately displayed and saved to the computer locally.

The software that has been developed is a tool to facilitate the testing. It allows for objective comparison between vehicle treatment schemes. State and local agencies and lighting manufacturers can use this tool to increase officer safety and to decrease tragic accidents associated with traffic stops.

Chapter 1. Introduction

More U.S. police officers are killed in collisions at roadside stops than are killed through felonious acts. According to the International Association of Chiefs of Police, roadside crashes killed 120 police officers from 1995 to 2004, an average of one officer every month.

Conspicuity of a squad car plays an important role in roadside safety. However, the level of conspicuity of a certain treatment of an emergency vehicle is not easily quantifiable. The purpose of this project was to determine a simple performance measure to quantify squad car conspicuity and to develop a simple testing strategy to collect and evaluate data pertaining to the performance measure.

The performance measure developed herein will quantify the performance of different exterior vehicle treatments in context of the “Ted Foss” move over law, Minnesota State statute 169.18 subd. 11. This law requires that as motorists pass a stationary emergency vehicle they must attempt to leave a vacant lane between them and the emergency vehicle. If it is not possible to safely vacate the lane, the vehicle is required to reduce speed. The propensity of the oncoming traffic to “move over” by vacating the lane nearer to the emergency vehicle will be measured by the relative volume of vehicles travelling in specific “zones” along the highway over the duration of the test. This performance measure has been developed as a means to accurately quantify the response of vehicles to the retro-reflective, lighting, and paint treatments. Until now, no work has been done to rigorously quantify and document the effects that different lighting, retro-reflective markings, and paint colors of an emergency vehicle have towards oncoming traffic during roadside stops.

Prior work in this area has taken considerably different approaches to determine the efficacy of emergency vehicle lighting. In [1], roadside stops were simulated, but the behavior of vehicles was recorded using video, which makes rigorous, accurate range and speed measurements difficult to obtain. Moreover, it makes experiments expensive to run because of the human capital needed to analyze video-based results. In this work, the use of radar eliminates the need for extensive human interaction, while providing higher-accuracy measurements. Radar provide accurate range, range rate, and azimuth angle to approaching vehicles, which simplify the data analysis process, and increase the accuracy of measurements.

In contrast to simulated roadside stops, the analyses undertaken in both [2] and [3] were performed to determine the microscopic human response to emergency lighting (color, intensity, and flash pattern), and the ability to detect a pedestrian in the presence and glare of nearby emergency lighting, respectively. Both [2] and [3] are relevant to the problem of roadside-stop safety, but approach the problem from the human perception perspective. In [2], the goal was to

> “…know about the positive (intended) effects of the lamps on vehicle conspicuity, as well as any negative (unintended) effects that the lamps may have on factors such as glare and driver distraction. This research was designed to provide information about how the colors and intensities of warning lamps influence both positive and negative effects of such lamps, in both daytime and nighttime lighting conditions.”

The focus of [3] was to determine the ability of a motorist to detect a pedestrian in the presence of local emergency vehicle lighting. Pedestrians can be visually lost in the glare of emergency lighting, making it difficult to impossible for an approaching motorist to see the safety worker. The severity of this problem, and recommendations for improvement, were suggested therein.

Lessons learned in [2] and [3] indicate to manufacturers which colors, patterns, intensities, and light sources represent a starting point for the analyses which can be undertaken using the radar-based approach. Optimum designs are more quickly determined when the initial solution space is narrowed.

Many troopers have opinions pertaining to what constitutes the safest treatment for patrol vehicles. The approach described here allows vehicle treatments to be analyzed with the intent of arriving at an optimum treatment, where optimum is measured by the move-over behavior of approaching traffic. Through the use of a software analysis program built specifically for this experiment, this optimum treatment can be determined with relative ease and with an empirical foundation. The program uses data obtained from six individual Delphi ESR radar sensors that are placed along the highway. This data is used to determine the relative volume of traffic within predetermined zones along the highway.

The report structure consists of five chapters and five supporting appendices. Subsequent to Chapter 1, the chapters discuss the testing facility, the variables that one must consider to ensure a valid test, the experimental procedure, and a final discussion involving recommendations and concluding remarks.

Chapter 2. The Testing Facility

The site of data collection for the study is the fully instrumented rural, thru-Stop expressway intersection of US Highway 52 and County Highway 9 in Goodhue County, approximately eight miles south of Cannon Falls, MN. The sensors located along the highway supply vehicle lane position data, covering a 400 meter span near the intersection. A plan view of the instrumentation positioning is shown below in Figure 1; it shows the layout of sensors at the intersection of U.S. 52 and CSAH 9 in Goodhue Country, MN. The figure also indicates where the emergency vehicle is to be parked during data collection. (It should be noted that the radar sensors' fields of view, represented by the yellow triangles in Figure 1 are not to scale. In actuality, the fields of view overlap much more to cover all locations along the highway in the testing zone.)

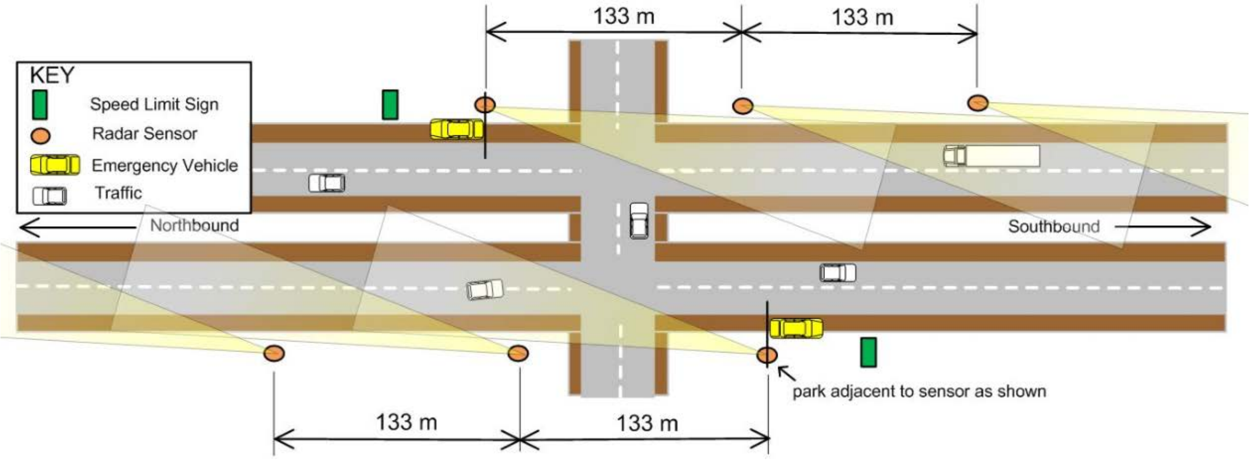


Figure 1. Testing facility schematic (not to scale).

The data collection system at this intersection allows for the identification of vehicle position and speed of travel. By extension, it also allows for tracking of lane changing and speed reduction behaviors. This will allow for the quantification of driver “move over” law adherence during the simulated traffic stops.

System performance specifications include [4]:

- Individual sensor vehicle detection rate - 99.998%
- Longitudinal lane position error - mean: 6.0 ft, standard deviation: 1.6 ft
- Lateral lane position error - mean: 1.3 ft, standard deviation: 1.2 ft
- Speed estimation error - mean: 1.1 MPH, standard deviation: 0.4 MPH

The second, portable system can be placed on the side of any straight two-lane highway. An example can be seen in Figure 2.

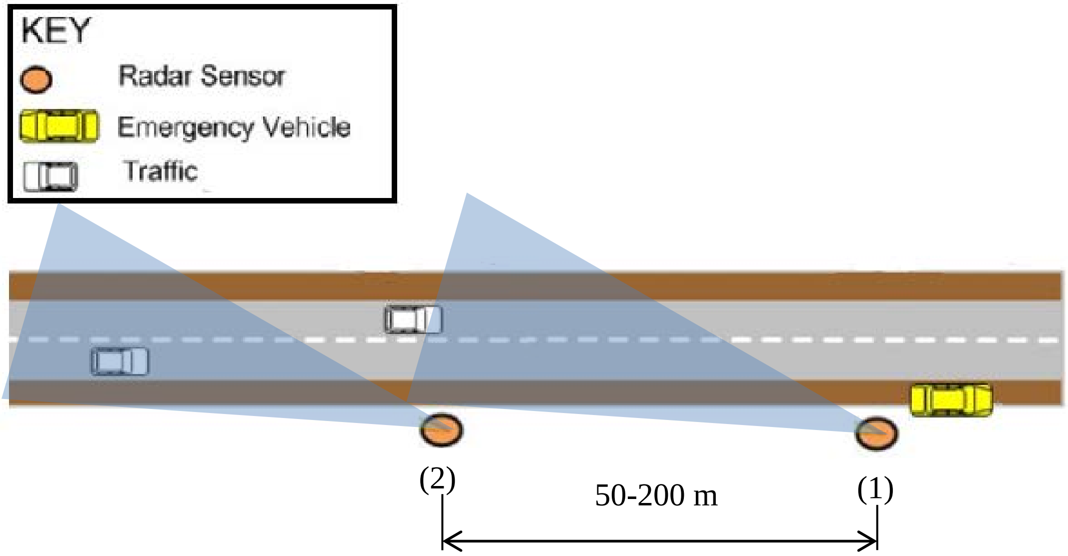


Figure 2. Portable testing schematic (not to scale).

This system is equipped with two UMRR9 SMS radars. System performance specifications include [4]:

- Longitudinal lane position error - mean: 4.0 ft, standard deviation 3.3 ft
- Lateral lane position error - mean: 3.8 ft, standard deviation: 3.1 ft
- Speed estimation error - mean: 0.6 MPH, standard deviation: 0.5 MPH

The computer is located at radar number 1, and communicates wirelessly with radar number 2. The distance between the radars is variable, and is decided by the user. The distance can be measured using lane stripe separation (50ft between stripes). This number is then entered into the computer before collection begins. Both radars are concealed in weatherproof cases with all necessary electronic mounted inside. Each radar unit is powered by a separate 12V battery.

Chapter 3. Experimental Variables

The following variables will have an effect on the results. The first three variables (1-3) can be considered primary variables since an optimum arrangement of these three variables is sought. The final three variables (4-6) can be considered secondary variables since they are not directly related to the treatment of the patrol vehicle.

1. Vehicle paint scheme
2. Vehicle retro-reflectivity
3. Vehicle lighting
4. Time of day when results are collected (dawn, daylight, dusk, night)
    - This also includes driving into or away from the sun
5. Weather (temperature, rain/sleet/snow, cloudy/sunny)
6. Traffic density

The variables above, with the exception of weather and traffic density, are fully controllable by the experimenter. The paint scheme includes the paint colors, design, and contrast. The paint scheme variable may be held constant using the maroon paint specified by the Minnesota State Legislature. Retro-reflectivity includes the reflectivity factor, color, design, and placement of retro-reflective tape on a patrol vehicle. Lighting includes all variations of light type, placement, orientation, brightness, and sequencing used on the patrol vehicle. The time of day is a crucial variable in this experiment due to the contrasting effects of paint, retro-reflectivity, and lighting between night and day. It is important that comparisons of variables 1-3 are made only on like conditions of variables 4-6. For example, once the parameters for variables 1-3 are established, variables 4-6 must be held approximately constant if any meaningful comparisons are to be drawn.

The four variables 1-4 above can be predetermined well in advance of an experiment. However, the weather conditions and the traffic density can only be estimated (albeit accurately) in advance of an experiment through weather forecasts and historical traffic data. Weather plays a fundamental role since driving habits change as a function of weather condition. In general, it can be assumed that traffic density is consistent during identical time periods (e.g. Monday afternoons), but undeterminable factors may, at times, prove this assumption inaccurate. Ultimately, drawing inferences from experiments with significantly different traffic densities should be avoided. The traffic density versus time of day was collected over two days in late May 2010, and is shown in Appendix C.

As a cautionary note, the inherent nature of the variability of conditions between tests adds complication to the interpretation of results. It is imperative that care be taken by the experimenter to limit the number of variable alterations in a given comparison between tests so that meaningful conclusions can be inferred; i.e., ensure not to compare “scheme A” tested during the day with “scheme B” tested at night.
It should be noted that tests must not be run day in and day out; it is possible that drivers may become accustom to the stationary squad, and in turn they may come to disregard the squad’s presence. This modified driver behavior could degrade the value of the results.

Chapter 4. Experimental Procedure

The experimental procedure is straightforward. Using a patrol vehicle outfitted in a treatment specified by the experimenter, a simulated traffic stop will be made. (The stop will be for a duration determined by the experimenter; for instance, 20 minutes.) While the stop is underway data is collected using the mainline radar sensors to record traffic volume in both the left lane and the right lane of each zone, where the zones are depicted in Figure 3. *The measure of performance is the percentage of the total traffic volume found in the right lane at each measurement zone 1-9.* The percentage of vehicles in the right lane should decrease as traffic approaches the patrol vehicle (as the zone number decreases as depicted in Figure 3).

The effect of the vehicle treatment as a means to move approaching traffic into the left lane or reduce speed is judged on this criterion. Figure 4 illustrates the expected measure of performance for a "normal" vehicle treatment. It can be seen that as traffic approaches the vehicle under test, the proportion of vehicles in the right lane decreases and the proportion of vehicles in the left lane increases. Appendix A and Appendix B illustrate the expected measure of move-over performance for a poor vehicle treatment and a good vehicle treatment, respectively. Appendix F provides the results of a test performed at the test intersection using a Chevrolet Tahoe equipped with a full suite of Whelen warning lights. As expected, the Tahoe using the full array of emergency lighting produced drastically different move-over behavior than did the Tahoe with no lights at all.

Using the programming languages Python and PostgreSQL, a website and analysis program were built. The tools associated with this website allow an experimenter to go to any web browser and enter the date and time of a test. This software supports efficient and accurate experimentation and facilitates the determination of an optimum configuration of the primary variables.

When test parameters are submitted, the analysis program goes to work by collecting, downloading, and analyzing the data received from the radar sensors. Once all of the data is analyzed, the experimenter will receive an e-mail containing the results of the experiment. The results can be seen numerically or in graphical format (the graph is constructed using the numerical results).

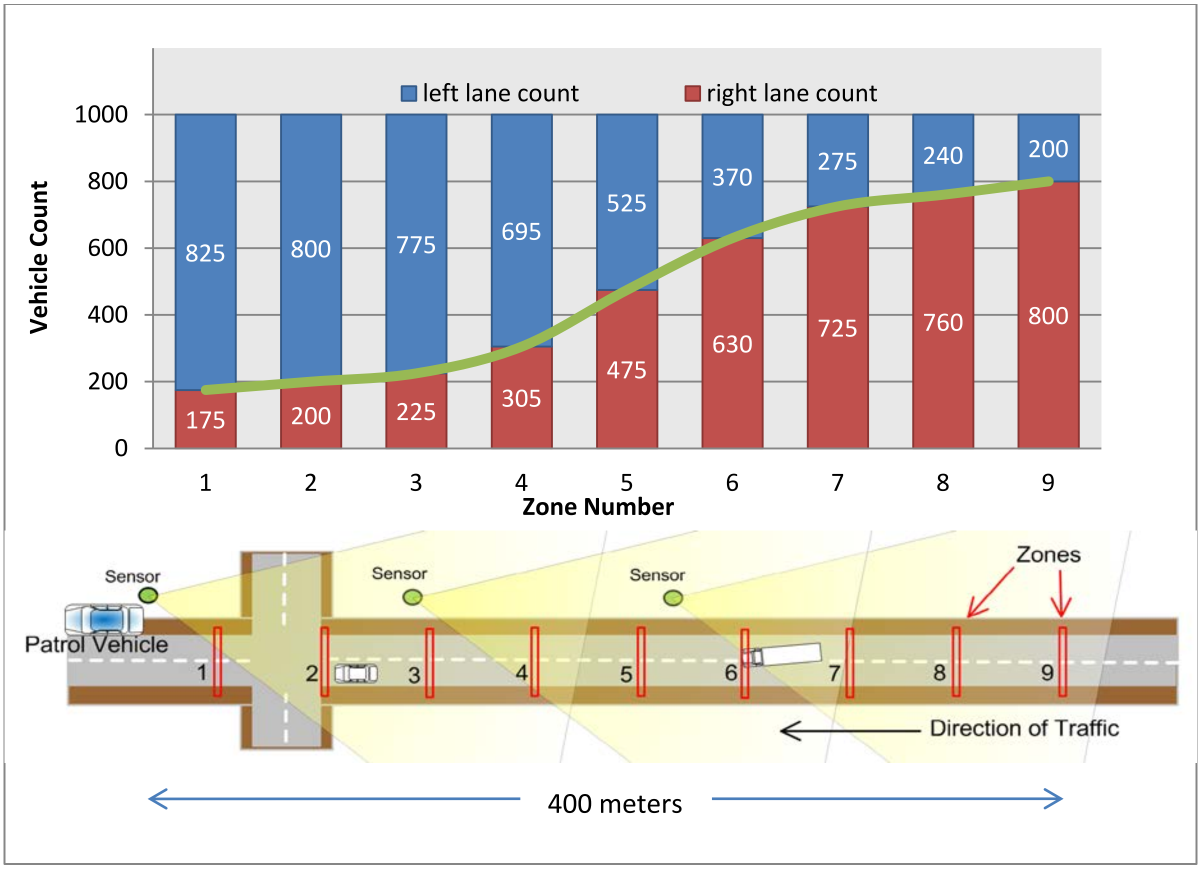


Figure 3. Zone configuration schematic.

An example graph can be seen in Figure 4 (an example of the numerical results can be found in Appendix E). The graph shown as Figure 4 was produced from data obtained under normal traffic conditions without the presence of an emergency vehicle at the roadside. As a result, it simply shows a baseline behavior, where approximately two-thirds of traffic travels in the right lane. However, a graph produced from the data obtained over the course of an experiment should depict a decrease in the relative number of vehicles in the right lane as the distance from the patrol vehicle decreases. Examples of such graphs can be seen in Appendix A and Appendix B. In addition to showing anticipated merging behavior, the results should show a decrease in average vehicle speed. However, it should be noted that a slight dip in vehicle speed is expected in Zone #1 due to the fact that some vehicles are slowly turning onto or off of the main-line highway. This dip is evident in the baseline data presented as Figure 4.

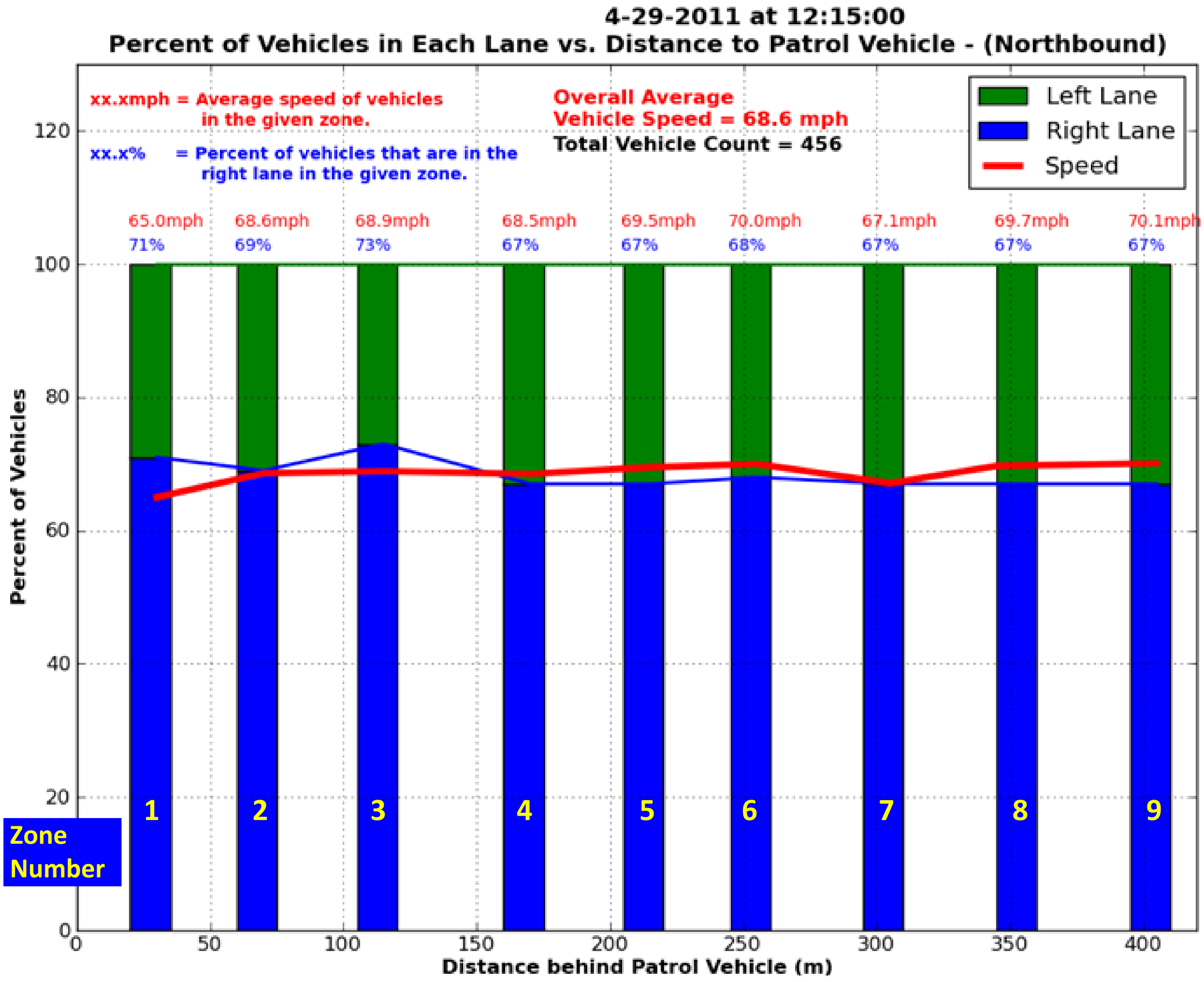


Figure 4. Normal traffic patterns with no simulated road-side stop.

A screen capture of the website where the information pertaining to a trial is to be entered is shown in Appendix D. The website address is www.patrol-lighting.me.umn.edu, and both a username and password are required for entry.

The portable system functions in a similar fashion to the original system. The two radars are set up at the user's discretion along the side of the highway, and the desired vehicle is parked near the first radar. The user enters the desired test length, the distance between radars, and then begins the test.

This program also uses the programming languages Python and PostgreSQL, but all of the processing is done locally on the netbook computer. This program adds an algorithm to identify where the lanes are, as the radars will be in different locations during each trial. The zone scheme is similar to the original, except the zones vary depending on the radar separation. The total distance covered by both radars is split evenly into 10 different zones.
The portable system produces very similar results. A screen shot of the formatting of the results can be seen in Figure 5.

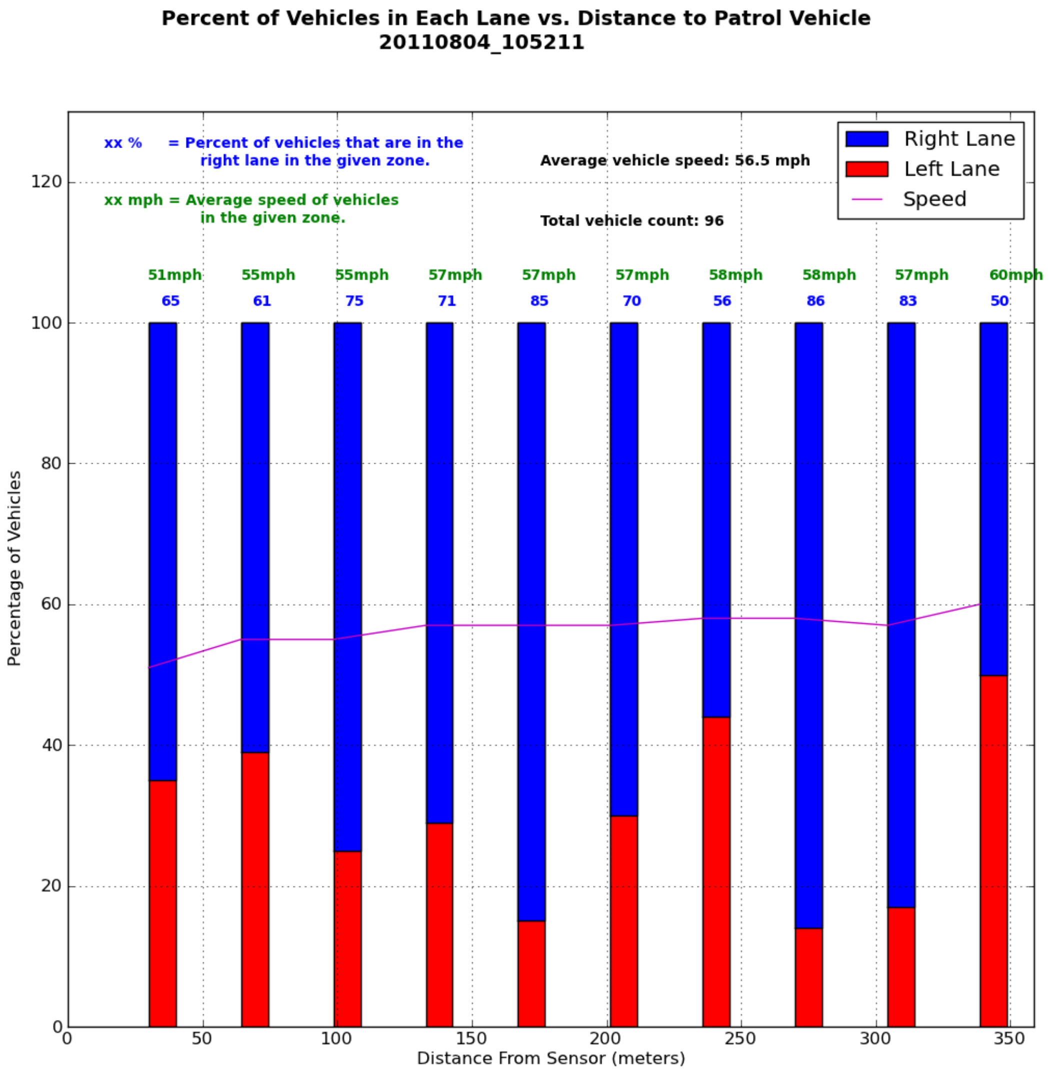


Figure 5. Screen capture of portable system results.

Chapter 5. Conclusion and Recommendations

Ultimately, the success of the project rests on stringent abidance to the experimental method. The importance of making only like comparisons between test vehicles cannot be overemphasized. To use the system to its potential, the protocol explained previously must be adhered to closely. The development of testing schemes will demand a great deal of practical creativity, and the development process must be conducted with a target testing strategy in mind.

The software that has been developed for this project is a tool to facilitate the testing and to allow for objective comparison between vehicle treatment schemes. In the end, the experimenters must use their own judgment in determining whether certain results are statistically significant enough to warrant further investment or possible implementation in the line of duty.

It is notable that the testing system documented herein is not limited to testing vehicle treatment schemes directly. It could be used by safety equipment manufacturers to objectively evaluate the performance of their products.

References

1. G. L. Ullman and D. Lewis, "Texas DOT vehicle fleet warning light policy," Texas Department of Transportation, Austin, TX, 2007.
2. M. J. Flannagan, D. F. Blower, and J. M. Devonshire, "Effects of Warning Lamp Color and Intensity on Driver Vision," SAE International, Warrendale, PA, 2008.
3. M. J. Flannagan and J. M. Devonshire, "Effects of Warning Lamps on Pedestrian Visibility and Driver Behavior," SAE International, Warrendale, PA, 2007.
4. J. Fischer, A. Menon, A. Gorjestani, C. Shankwitz, and M. Donath, "Range sensor evaluation for use in Cooperative Intersection Collision Avoidance Systems," *Vehicular Networking Conference (VNC), 2009 IEEE,* 2009.

Appendix A: Good “Move Over” Behavior

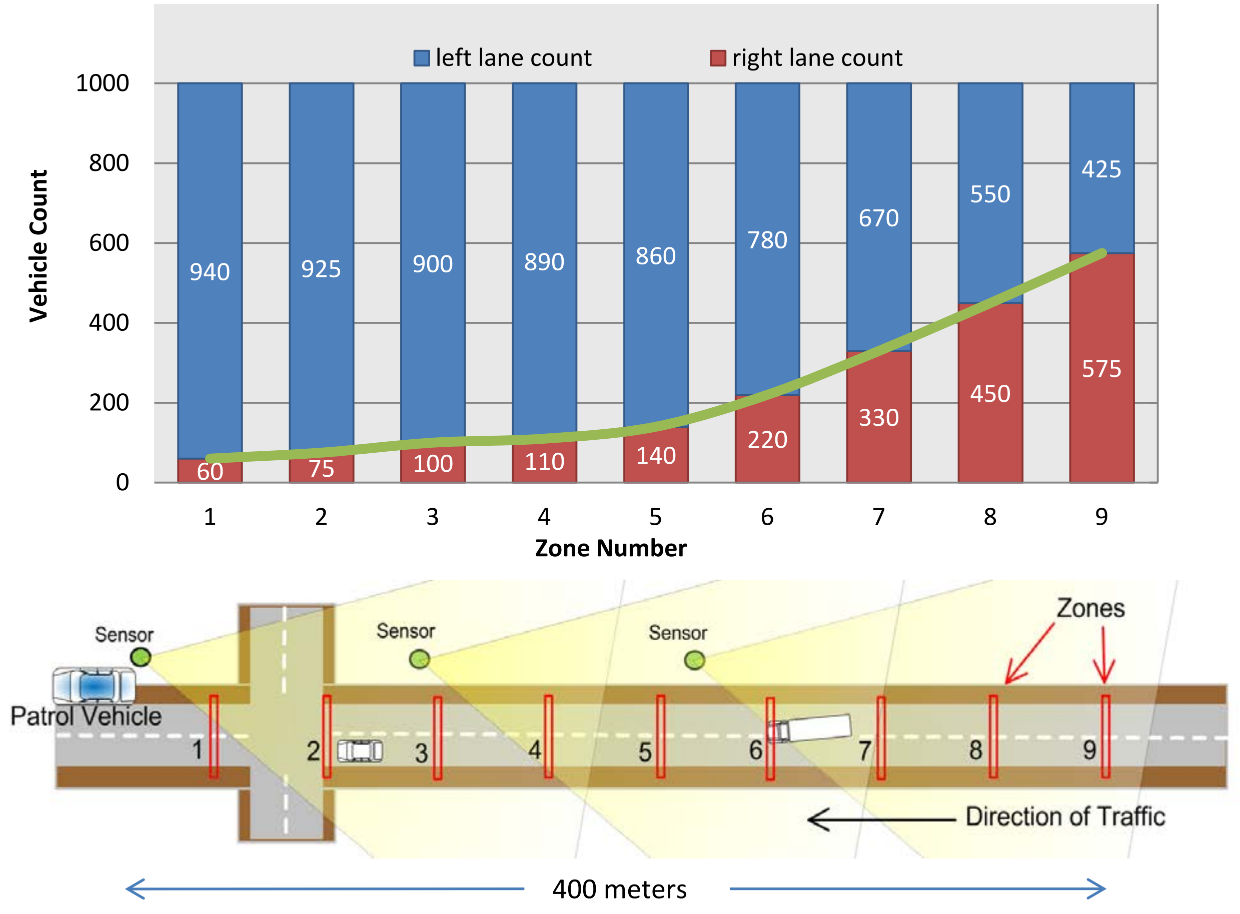


Figure A-1. Representative performance measure for good “move over” behavior.

Appendix B: Poor “Move Over” Behavior

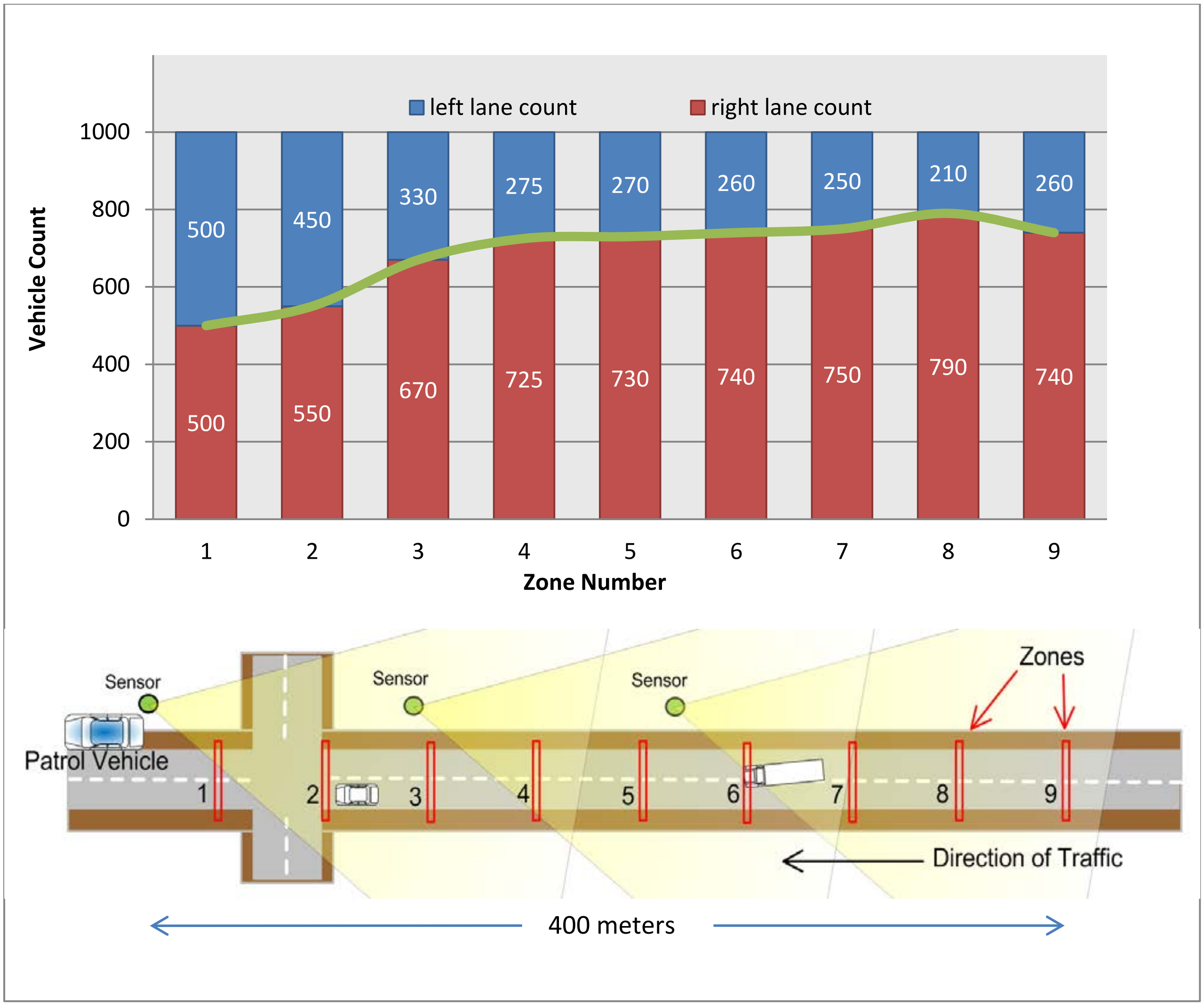


Figure B-1. Representative performance measure for poor “move over” behavior.

Appendix C: Traffic Density

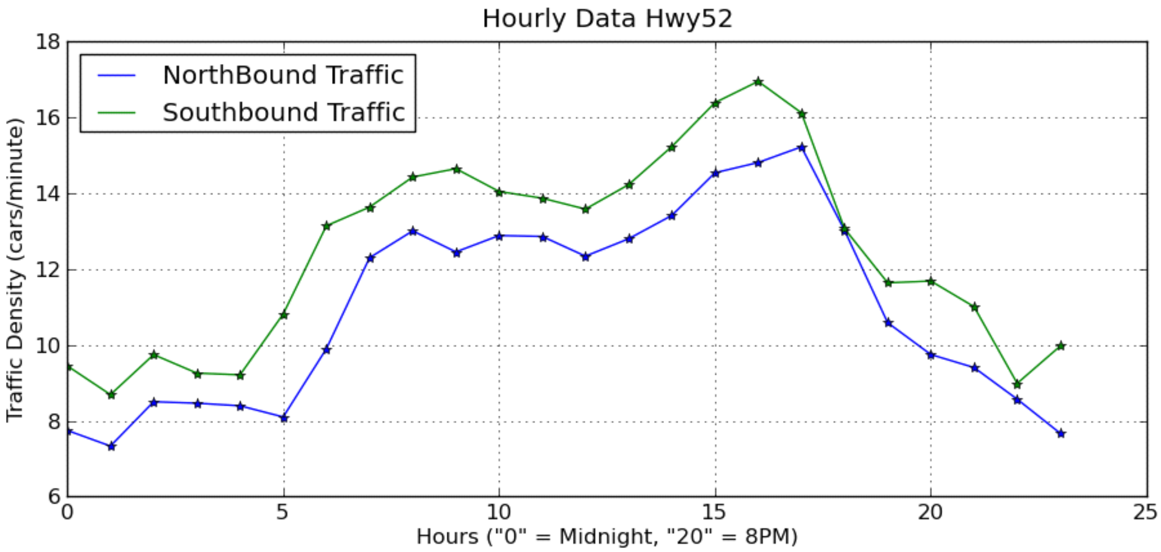
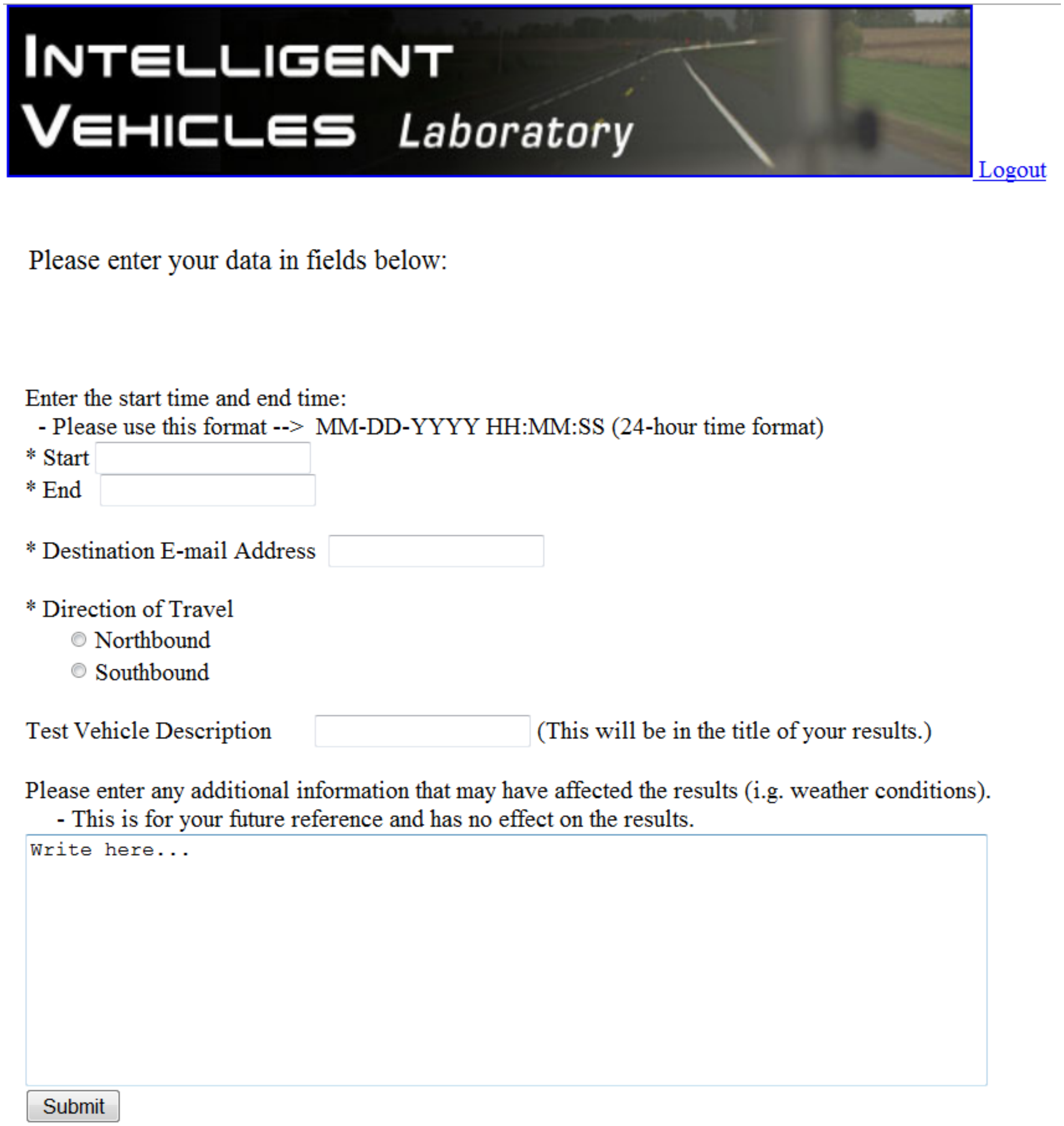


Figure C-1. Traffic density vs. time of day.

Appendix D: Data Collection Page



Please enter your data in fields below:

Enter the start time and end time:
- Please use this format --> MM-DD-YYYY HH:MM:SS (24-hour time format)

* Start
* End

* Destination E-mail Address

* Direction of Travel
○ Northbound
○ Southbound

Test Vehicle Description (This will be in the title of your results.)

Please enter any additional information that may have affected the results (i.g. weather conditions).
- This is for your future reference and has no effect on the results.

Write here...

Figure D-1. Front page of trooper safety website providing the experimenter instructions.

Appendix E: Example of Numerical Results

```
total vehicle count = 133.0 vehicles
average vehicle density = 8.9 vehicles per minute
zone numbers [near patrol vehicle...far from patrol vehicle]: [1, 2, 3, 4, 5, 6, 7, 8, 9]
distance of zone behind patrol vehicle (meters) - different for northbound and southbound:
        [25, 55, 100, 175, 215, 250, 320, 370, 410]
right lane vehicle count per zone: [23, 13, 14, 17, 17, 23, 21, 26, 38]
average speed per zone:
        ['58.8 mph', '62.9 mph', '63.1 mph', '63.7 mph', '65.0 mph', '65.4 mph', '62.8 mph', '65.8
        mph','66.3 mph']
```

Appendix F: Test Results for Whelen Test Vehicles

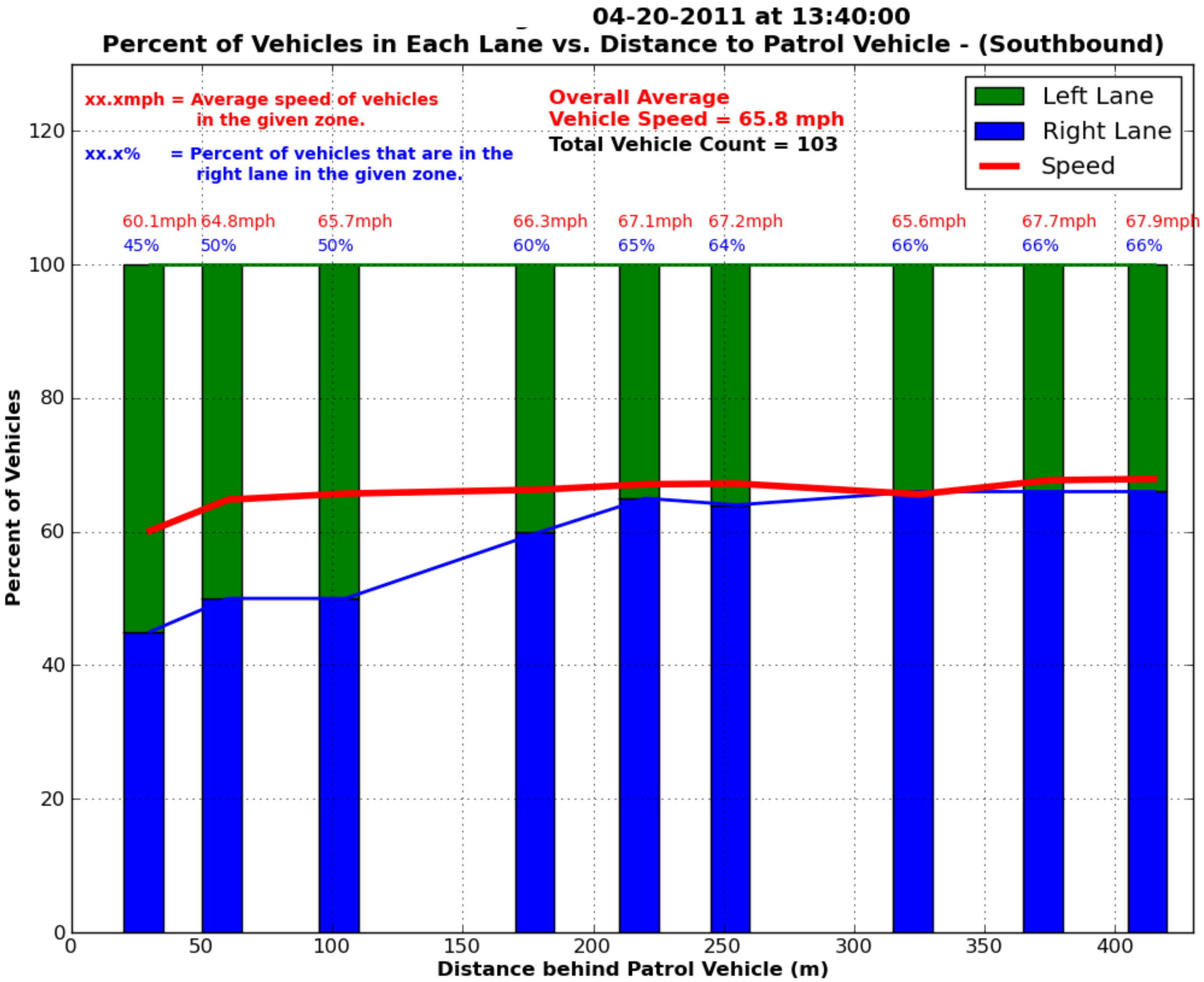


Figure F-1. Test results for Whelen test vehicle with no lights turned on.

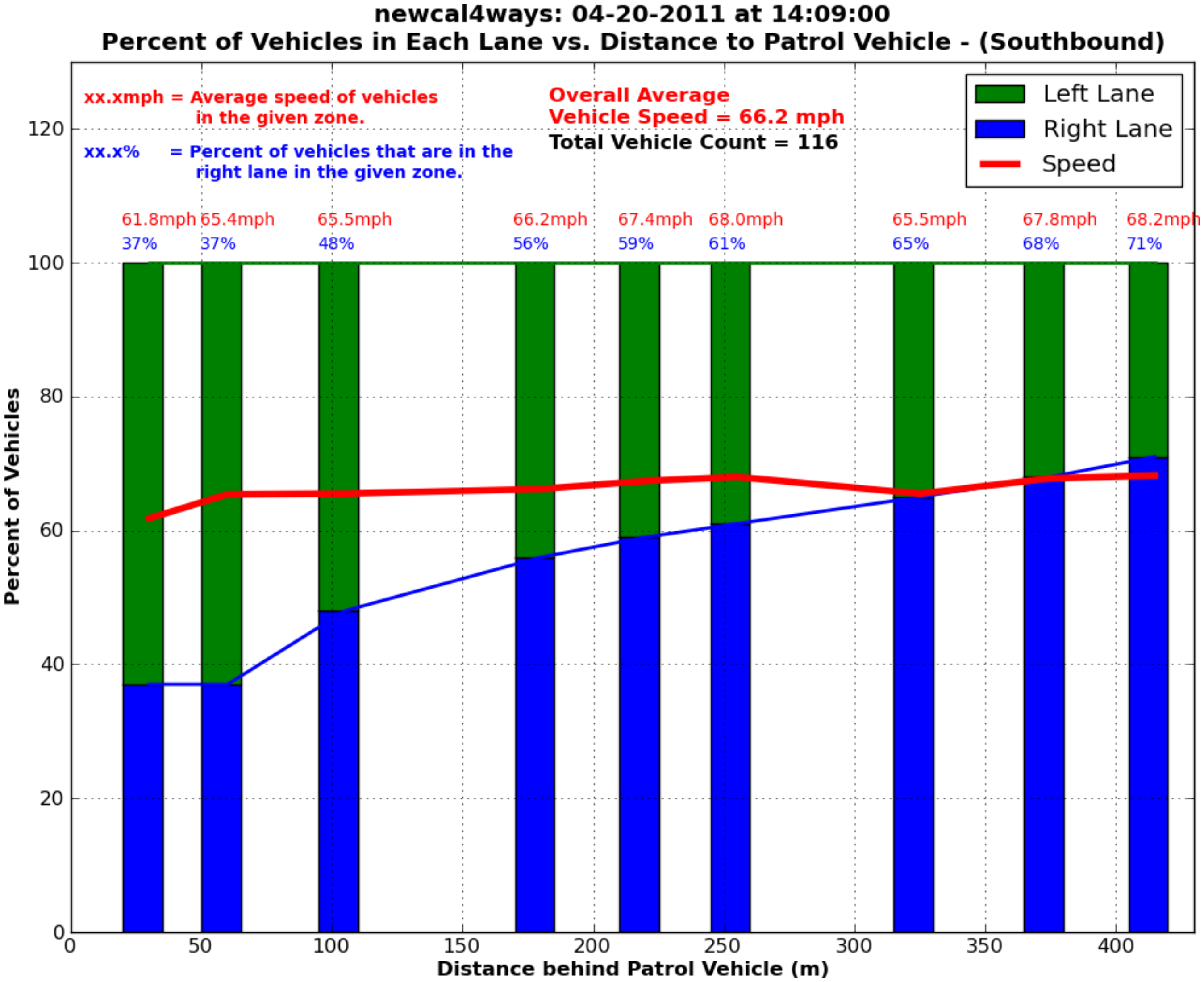


Figure F-2. Test results for Whelen test vehicle with four-way flashers.

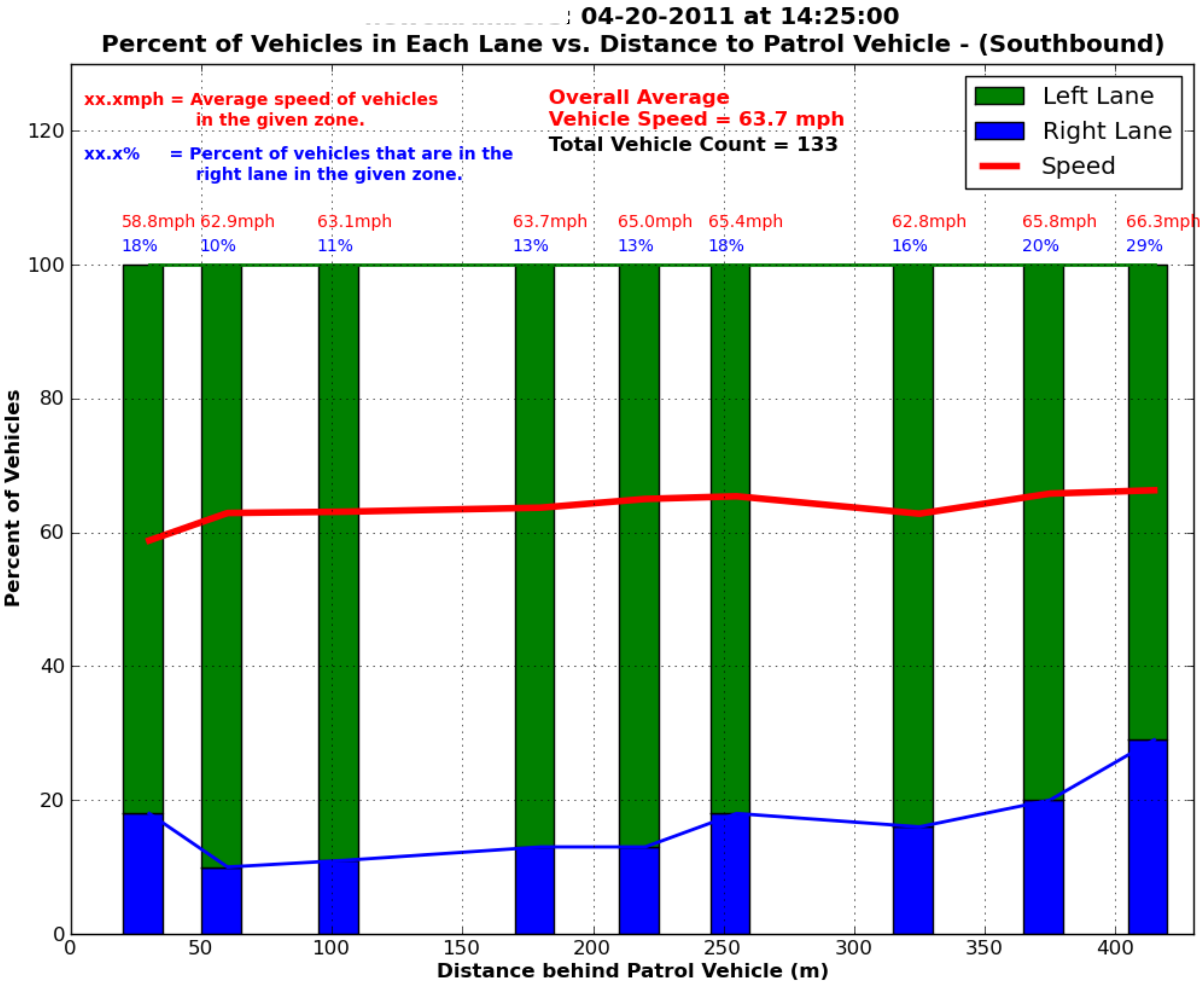


Figure F-3. Test results for Whelen test vehicle with flashing amber lights.

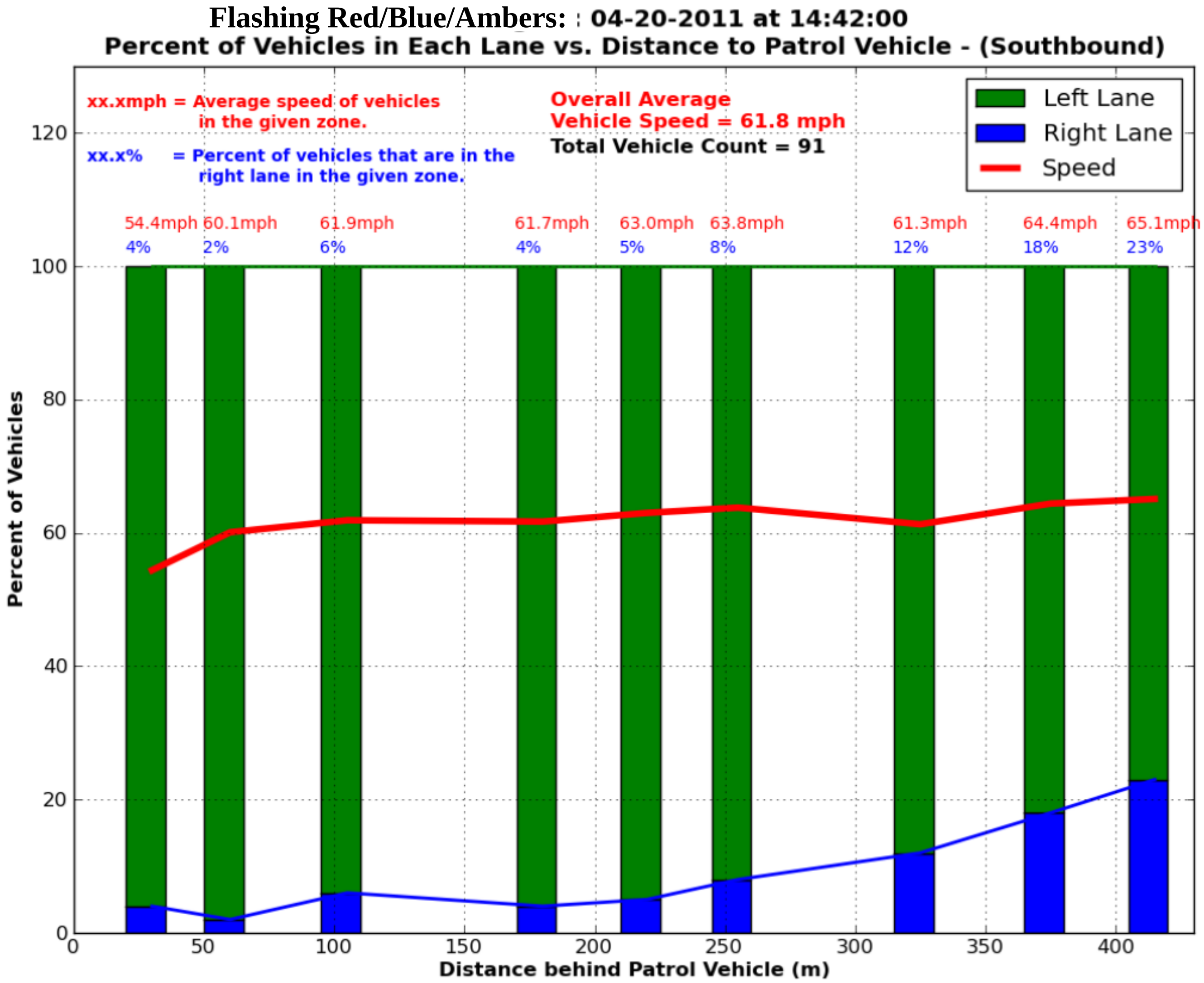


Figure F-4. Test results for Whelen test vehicle with flashing blue/red/amber lights.