TANTALA ASSOCIATES, LLC
CONSULTING ENGINEERS

A STUDY OF THE RELATIONSHIP BETWEEN DIGITAL BILLBOARDS AND TRAFFIC SAFETY IN HENRICO COUNTY AND RICHMOND, VIRGINIA

SUBMITTED TO

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KEY POINTS

- More than 7 years of accident data comparisons
- Ten locations with 14 digital billboard faces with 10 second duration times
- Data show no statistically significant increase in accident rates, using before and after comparisons and using an Empirical Bayes Method Analysis for the actual and predicted comparisons
- Comparisons of driver age (young/elderly) and time of day (daytime/nighttime) are neutral factors

DIGITAL KEY

1	Rte 250 / West Broad Street
2	East Parham Road
3	Rte 250 / West Broad Street
4	Interstate 64
5	Interstate 195
6	East Laburnum Avenue
7	East Laburnum Avenue
8	Rte 360 / Mechanicsville Turnpike
9	Interstate 64
10	Interstate 95

Figure 1.
Digital Billboard Locations analyzed in Henrico County and Richmond, Virginia

<u>TOC</u>

More than 7 years of data ...

... no statistically significant relationship with the occurrence of accidents ...

... 10-second duration times ...

OVERVIEW

The purpose of this study is to **examine the statistical relationship between digital billboards and traffic safety in Henrico County and Richmond, Virginia**. This study analyzes traffic and accident data along routes near **10 locations with 14 digital billboard faces** (see Figure 1) with traffic volumes on roads collectively representing approximately 154 million vehicles per year. The study uses official data as collected, complied and recorded independently by municipal police departments, Henrico County and the Virginia Department of Transportation.

The study includes more than **seven years of accident data** representing approximately 40 thousand accidents near ten locations in Richmond and Henrico County. The billboards were converted to digital format between 2006 and 2009 and allow periods of comparison as long as 7.3 years (88 months).

Temporal (*when and how frequently*) and spatial (*where and how far*) statistics are summarized near billboards within multiple vicinity ranges as large as one-half mile for areas that are upstream and downstream of the billboards. Subsets of daytime and nighttime accidents and driver age are analyzed for before and after comparisons.

Additionally, an Empirical Bayes Method (EBM) analysis is performed to estimate the number of accidents that could statistically be expected without the introduction of digital signs. This method is the basis of the safety analysis and science-based, predictive models introduced within the 2010 *Highway Safety Manual* of the American Association of State Highway Official (AASHTO, Reference 14). This report establishes benchmarks for the basis of accident records at pre-digital locations and also uses other comparison sites in Henrico County and Richmond.

The overall conclusion of the study is that **the digital billboards in Richmond, Virginia have no statistically significant relationship with the occurrence of accidents**. This study also finds that the age of drivers (younger/elderly) and the time of day (daytime/nighttime) are neutral factors which show no significant increase in accident rates near the digital billboards. These conclusions are based on Police Department data and an objective statistical analysis; **the data show no significant increase in accident rates**.

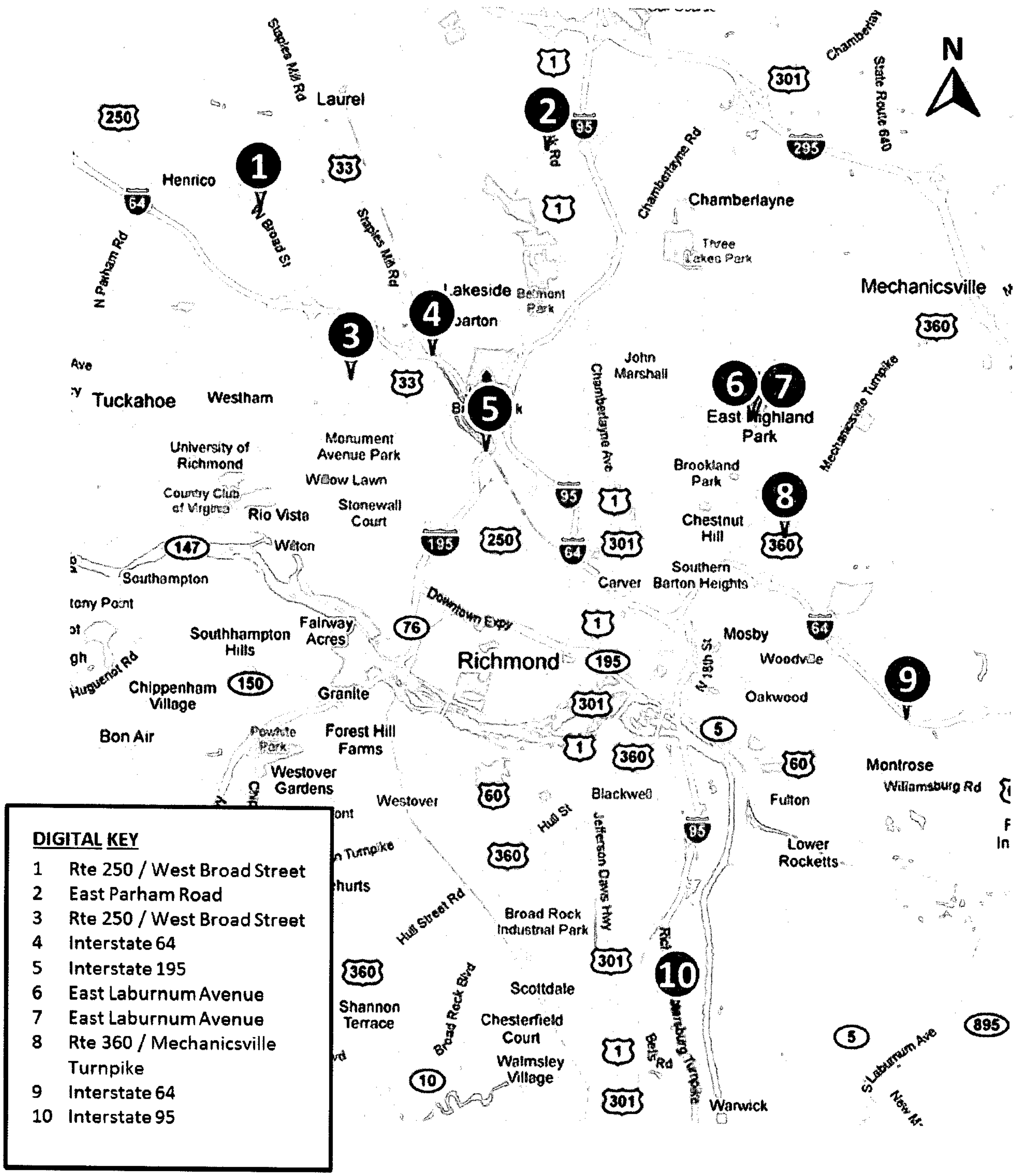


Figure 2.
Digital Billboard Locations analyzed in Henrico County and Richmond, Virginia. Each location studied has a 10 second duration time.

The static display on each of these digital billboards have "duration times" of 10 seconds.

STUDY REGION

This portion of the Greater Richmond Area was chosen as a study region, because it has multiple digital billboards in close proximity that were in service for extended periods of time. The roads adjacent to these billboards are heavily traveled (approximately 423 thousand vehicles traveled per day collectively on the sections of road near the digital billboards in Figure 2).

The study area of Henrico County and the City of Richmond, a portion of the Greater Richmond Area in Virginia, is situated in the central part of the State, and collectively has an area of approximately 308 square miles, has a population of 352 thousand people and has 174 thousand households (2000 census).

Several federal and state highways allow entry to the Greater Richmond Area as it is situated at the junction of east-west Interstate 64 and north-south Interstate 95, two of the most heavily traveled highways in the state. Henrico County is one of only two counties in Virginia that maintain their own roads. Interstate highways include Interstate 64, Interstate 95, and Interstate 295. Interstate 64 runs east-west and overlaps Interstate 95 for several miles in Richmond. Interstate 195 is a short spur from north of downtown Richmond, south into the downtown. Interstate 295 is a bypass to the east of Richmond and extends from Interstate 95 south of Petersburg. Other major highways include U.S. Route 1, U.S. Route 250 and U.S. Route 360.

BILLBOARD CHARACTERISTICS

Digital billboards display static messages which, when viewed, resemble conventional painted or printed billboards. With digital technology, a static copy displays for a duration and includes no animation, flashing lights, scrolling, or full-motion video. The static display of each of these digital billboards has a "duration time" of 10 seconds. The digital billboards use red, green, and blue light-emitting-diode (LED) technology to present text and graphics. The digital billboards compensate for varying light levels, including day and night viewing, by automatically monitoring and adjusting overall display brightness and gamma levels. A photocell is mounted on each digital billboard to measure ambient light. Each of the digital billboards that were studied is owned and operated by *Lamar*.

Billboard Location	Location	Configuration	Side of Road	Digital Facing Direction	Reader Side	Face Size (ft)	Duration Time (seconds)
1	**Rte 250 / West Broad Street** at 7912 West Broad Street (37° 37' 25.194", -77° 31' 40.515")	Free standing, Flag, Vee	N	E W	right cross	11x23 10.5x36	10 10
2	**East Parham Road** 0.25 miles west of Interstate 95 (37° 38' 6.7668", -77° 27' 40.381")	Free standing, Flag, Vee	N	W	cross	11x22	10
3	**Rte 250 / West Broad Street** at 5912 West Broad Street (37° 35' 32.607", -77° 30' 22.834")	Free standing, Center-mount with offset, Vee	N	E	right	11x23	10
4	**Interstate 64** 0.2 miles east of Staples Mill Road (37° 35' 49.729", -77° 29' 14.935")	Free standing, Center-mount, Vee	N	E	right	12.5x40	10
5	**Interstate 195** south of the Insterstates 64 and 95 intersection (37° 34' 45.757", -77° 28' 29.744")	Free standing, Flag, Vee	W	S N	cross right	14x36 14x36	10 10
6	**East Laburnum Avenue** 0.07 miles east of Carolina Avenue (37° 35' 7.3211", -77° 24' 48.898")	Free standing, Center-mount, Vee	N	E	right	10x21	10
7	**East Laburnum Avenue** 0.12 miles east of Carolina Avenue (37° 35' 7.3427", -77° 24' 45.050")	Free standing, Center-mount, Back-to-Back	N	E	right	10.5x36	10
8	**Rte 360 / Mechanicsville Turnpike** 0.3 miles north of Interstate 64 (37° 33' 50.011", -77° 24' 19.292")	Free standing, Center-mount, Back-to-Back	W	S N	cross right	14x28 14x28	10 10
9	**Interstate 64** 0.6 miles west of South Laburnum Avenue (37° 31' 50.091", -77° 22' 36.814")	Free standing, Center-mount, Vee	S	E	cross	12.5x42	10
10	**Interstate 95** 0.6 miles north of Bells Road / Rte 161 (37° 28' 32.231", -77° 25' 49.227")	Free standing, Center-mount, Vee	W	N S	right cross	14x48 14x48	10 10

Figure 3.
Digital Billboard Direction, Sizes and Other Sign Characteristics

Of the ten, digital-billboard locations studied, nine are located in Henrico County and one is located in the City of Richmond. Several additional digital locations were installed in the study region in 2010. These newer locations are not included as in this study because data collection would be limited to 2009; 2010 accident data was not available at the time of this study.

The digital, billboard locations are numbered 1 to 10 with 14 billboard faces. The ten locations in Henrico County and Richmond are shown in Figures 1, 2 and 3 which summarize direction, configuration and other sign characteristics. The digital boards and their surroundings were observed during day and night conditions. A majority of the digital billboards are freestanding single-pole, structures with one digital face; four locations have two digital boards on the same upright.

Figure 4 summarizes the conversion dates. Nine of the 14 billboard faces were converted to digital format prior to 2008 and the others were converted on various dates in 2008 and 2009. These dates allow for before/after comparisons as long as 7.3 years (or 88 months). Additional billboard-location photos, aerials, and map references for each digital location are included in this report as Figures 5 to 14.

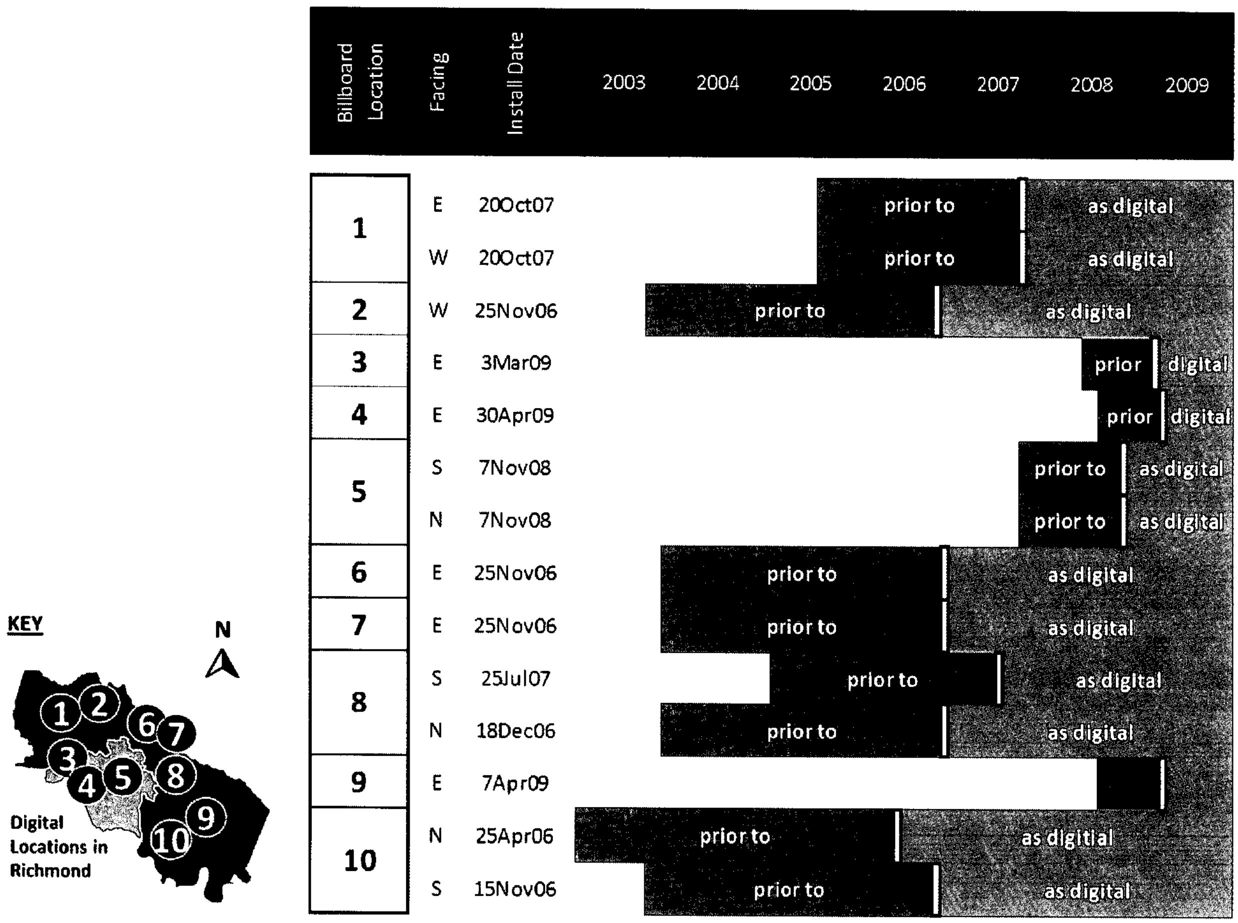


Figure 4.
Digital billboard Conversion Dates and Comparison Timelines for Digital Locations in Henrico County and Richmond, Virginia

Location No. 1 is on the north side of Route 250, at 7912 West Broad Street. The structure is a double-face, free standing, flag, vee configuration. The west face is a digital bulletin and is a right-hand reader. The west face (which faces east) has a 10.5x36 size and was a new build on 27Oct07 at this location. The east face (which faces west) is a digital poster and a cross reader. The east face has an 11x23 size and was a new build on 27Oct07. Each face is operated by Lamar, and has a duration time of 10 seconds. Figure 5a is a photo of the south digital face. Figure 5b shows the location in an oblique aerial.

Figure 5. Location No. 1 (5a, left) View on Route 250; inset shows opposite-face digital, (5b, right) Oblique Aerial of location

Location No. 2 is on the north side of East Parham Road, approximately 0.25 miles west of Interstate 95. The structure is a face, free standing, flag configuration. The east face is a digital poster and a cross reader. The face was converted from a conventional format on 25Nov06 using the existing location. The face is operated by Lamar, and has an 11x22 size with a duration time of 10 seconds. Figure 6a is a photo of the digital face. Figure 6b shows the location in an oblique aerial.

Figure 6. Location No. 2 (6a, left) View on East Parham Road North, (6b, right) Oblique Aerial of location

Location No. 3 is on the north side of Route 250, at 5912 West Broad Street. The structure is a double-face, free standing, center-mount with an offset, vee configuration. The west face is a digital poster and a right-hand reader. The north face was a new build on 3Mar09. The face is operated by Lamar, and has an 11x23 size with a duration time of 10 seconds. Figure 7a is a photo of the digital face. Figure 7b shows the location in an oblique aerial.

Figure 7. Location No. 3 (7a, left) View on Route 250, (7b, right) Oblique Aerial of location

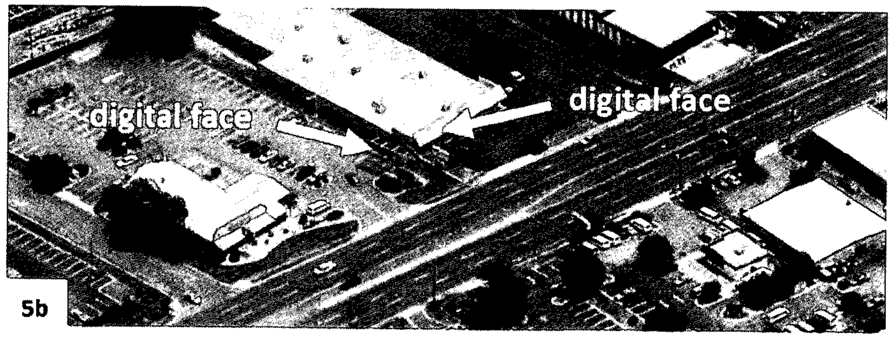
Location No. 4 is on the north side of Interstate 64, approximately 0.2 miles east of Staples Mill Road. The structure is a double-face, free standing, center-mount, vee configuration. The west face is a digital bulletin and a right-hand reader. The face was a new build on 30Apr09 at this location. The face is operated by Lamar, and has a 12.5x40 size with a duration time of 10 seconds. Figure 8a is a photo of the digital face. Figure 8b shows the location in an oblique aerial.

Figure 8. Location No. 4 (8a, left) View on Interstate 64, (8b, right) Oblique Aerial of location

Location No. 5 is on the west side of Interstate 195 just south of the intersection of the Interstate 64 and Interstate 95. The structure is a double-face, free standing, flag, vee configuration. The north face is a digital bulletin and a cross reader. The north and south faces were converted from conventional format on 7Nov08. Each face is operated by Lamar and has a 14x36 size with a duration time of 10 seconds. Figure 9a is a photo of the digital face. Figure 9b shows the location in an oblique aerial.

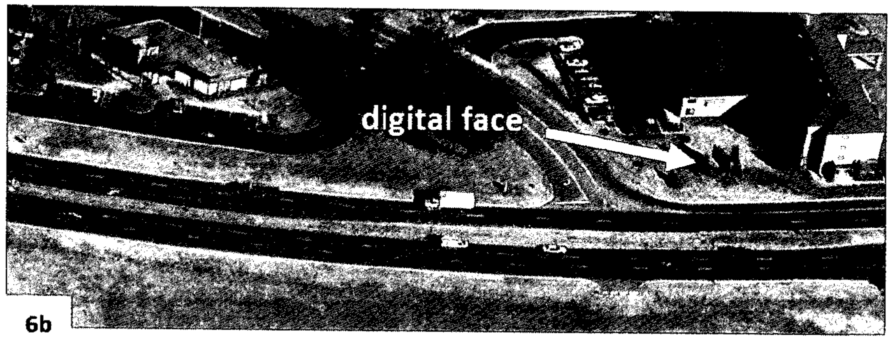
Figure 9. Location No. 5 (9a, left) View on Interstate 195, inset shows opposite-face digital (9b, right) Oblique Aerial of location


5a

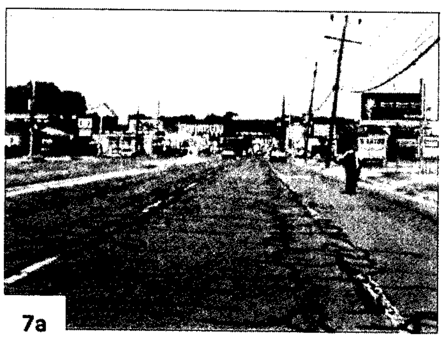


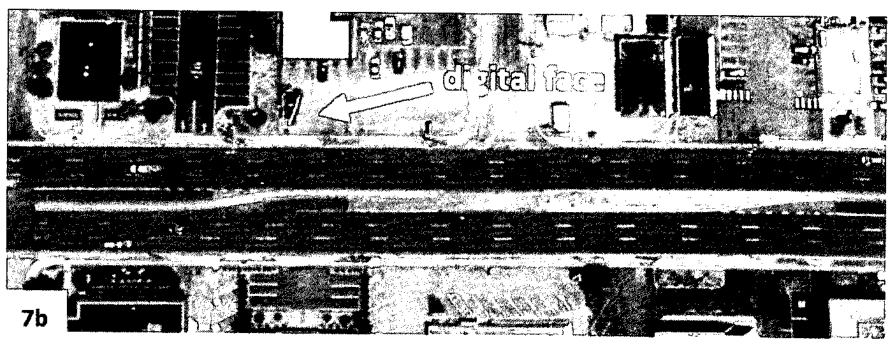
5b


6a

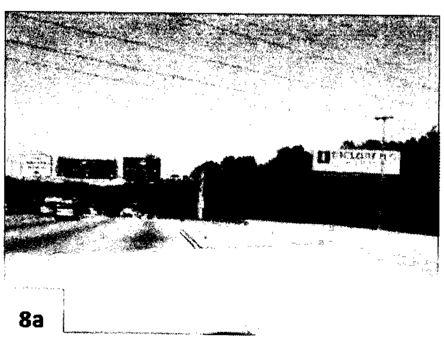


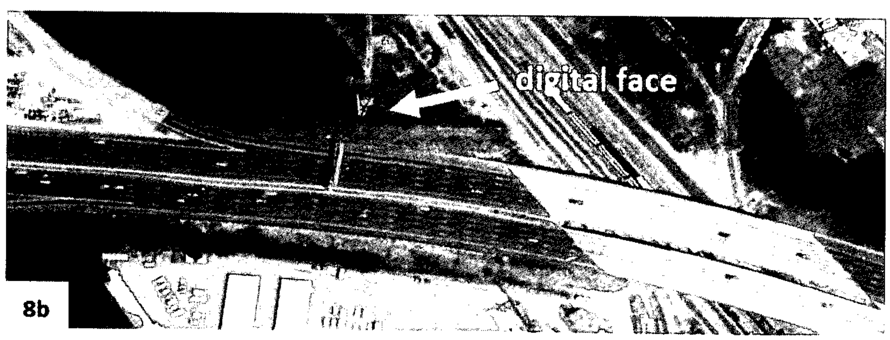
6b


7a

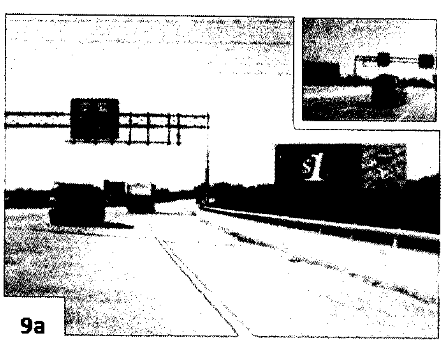


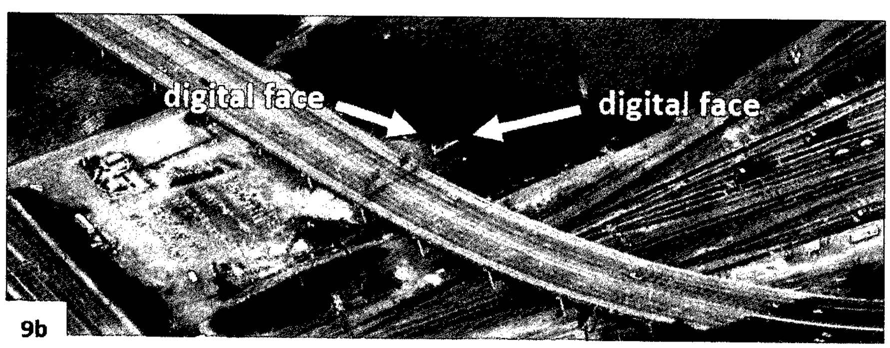
7b


8a



8b


9a



9b

Location No. 6 is on the north side of East Laburnum Avenue, approximately 0.07 miles east of Carolina Avenue. The structure is a double-face, free standing, center-mount, vee configuration. The west face is a digital poster and a right-hand reader. The face was converted from a conventional format on 25Nov06 using the existing location. The face is operated by Lamar and has a 10x21 size with a duration time of 10 seconds. Figure 10a is a photo of the digital face. Figure 10b shows the location in an oblique aerial.

Figure 10. Location No. 6 (10a, left) View on East Laburnum Avenue, (10b, right) Oblique Aerial of location

Location No. 7 is also on the north side of East Laburnum Avenue, approximately 0.12 miles east of Carolina Avenue. The structure is a double-face, free standing, center-mount, back-to-back configuration. The west face is a digital poster and a right-hand reader. The west face was a new build on 25Nov06 at this location. The face is operated by Lamar and has a 10.5x36 size with a duration time of 10 seconds. Figure 11a is a photo of the digital face. Figure 11b shows the location in an oblique aerial.

Figure 11. Location No. 7 (11a, left) View on East Laburnum Avenue, (11b, right) Oblique Aerial of location

Location No. 8 is on the west side of the Route 360 (Mechanicsville Turnpike), approximately 0.3 miles north of Interstate 64. The structure is a double-face, free standing, back-to-back, center-mount configuration. The north face is a digital poster and a cross reader and was converted from a conventional format on 25Jul07. The south face is a digital poster and a right-hand reader. The south face was converted from a conventional format on 18Dec06. Each face is operated by Lamar and has a 14x28 size with a duration time of 10 seconds. Figure 12a is a photo of the digital face. Figure 12b shows the location in an oblique aerial.

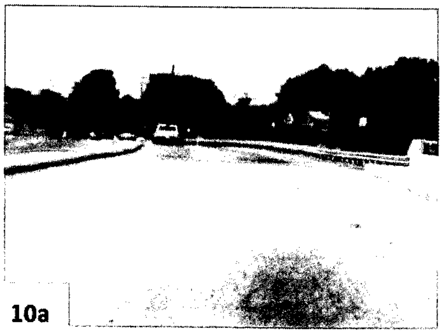
Figure 12. Location No. 8 (12a, left) View at Route 360 (Mechanicsville Turnpike), inset shows opposite-face digital, (12b, right) Oblique Aerial of location

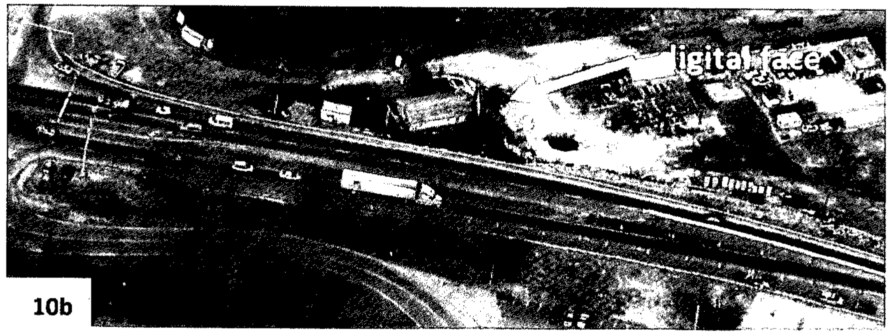
Location No. 9 is on the south side of Interstate 64, approximately 0.6 miles west of South Laburnum Avenue. The structure is a double-face, free standing, center-mount, vee configuration. The west face is a digital poster and a cross reader. The face is operated by Lamar, has a 12.5x42 size with a duration time of 10 seconds, and was converted on 7Apr09. Figure 13a is a photo of the east digital face. Figure 13b shows the location in an oblique aerial.

Figure 13. Location No. 9 (13a, left) View on Interstate 64, (13b, right) Oblique Aerial of location

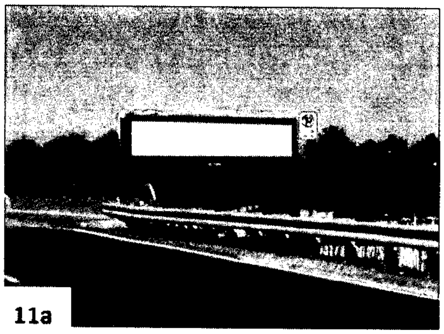
Location No. 10 is on the west side of Interstate 95, approximately 0.6 miles north of Bells Road (Route 161). The structure is a double-face, free standing, center-mount, vee configuration. The south face is a digital poster and a right-hand reader. The south face was converted from a conventional format on 25Apr06. The north face is a digital poster and a cross reader. The north face was converted from a conventional format on 15Nov06 using the existing location. Each face is operated by Lamar and has a 14x48 size with a duration time of 10 seconds. Figure 14a is a photo of the digital face. Figure 14b shows the location in an oblique aerial.

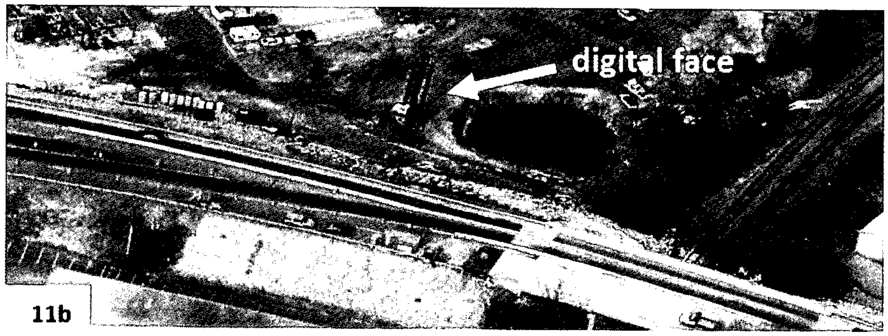
Figure 14. Location No. 10 (14a, left) View on Interstate 95, inset shows opposite-face digital (14b, right) Oblique Aerial of location


10a

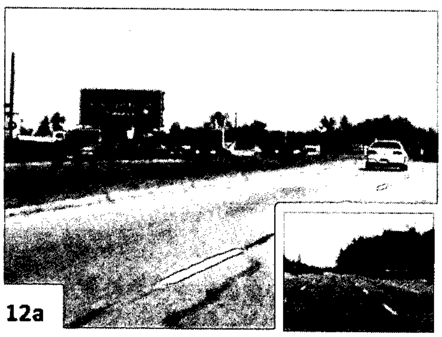


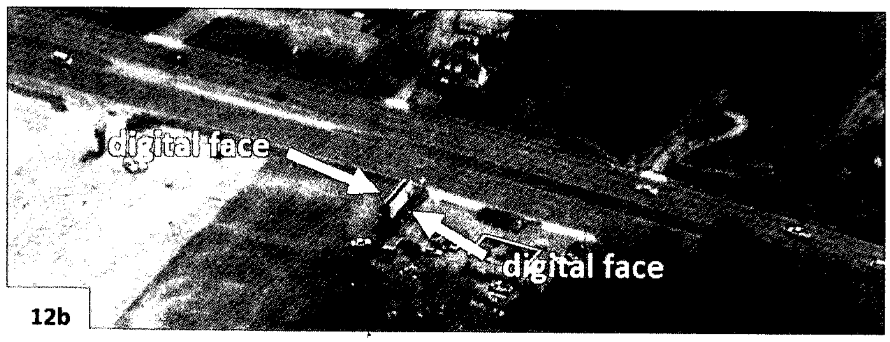
10b


11a

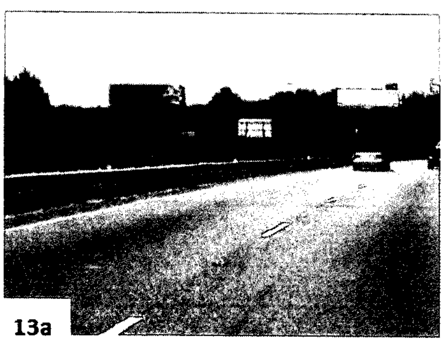


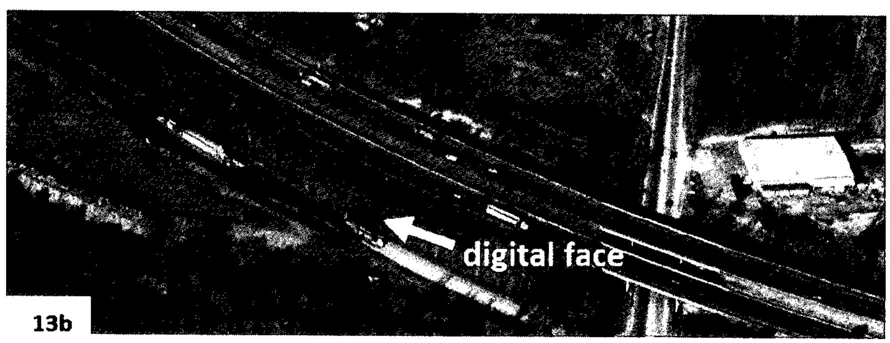
11b


12a

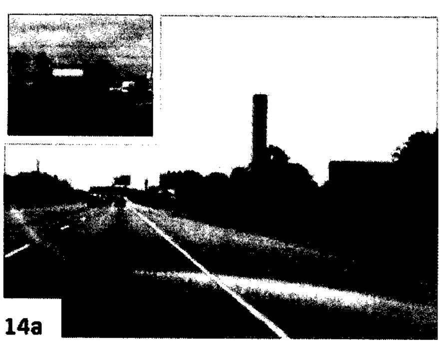


12b


13a



13b


14a

14b

AADT ranges individually near the 10 digital locations from 27 to 100 thousand vehicles per day, or equivalently 9 to 36 million vehicles per year.

TRAFFIC VOLUME DATA

Traffic volume data for Henrico County and Richmond were obtained from the Virginia Department of Transportation (VDOT) and include the annual average daily traffic (AADT), which is the average of 24-hour counts collected throughout the year. The AADT volumes were recorded for the Henrico County and Richmond between 2004 and 2009.

The AADT values are summarized in Figure 15. AADT ranges individually near the 10 digital locations from 27 to 100 thousand vehicles per day, or equivalently 9 to 36 million vehicles per year. For all locations, this collectively represents approximately 423 thousand vehicles per day or 154 million vehicles per year.

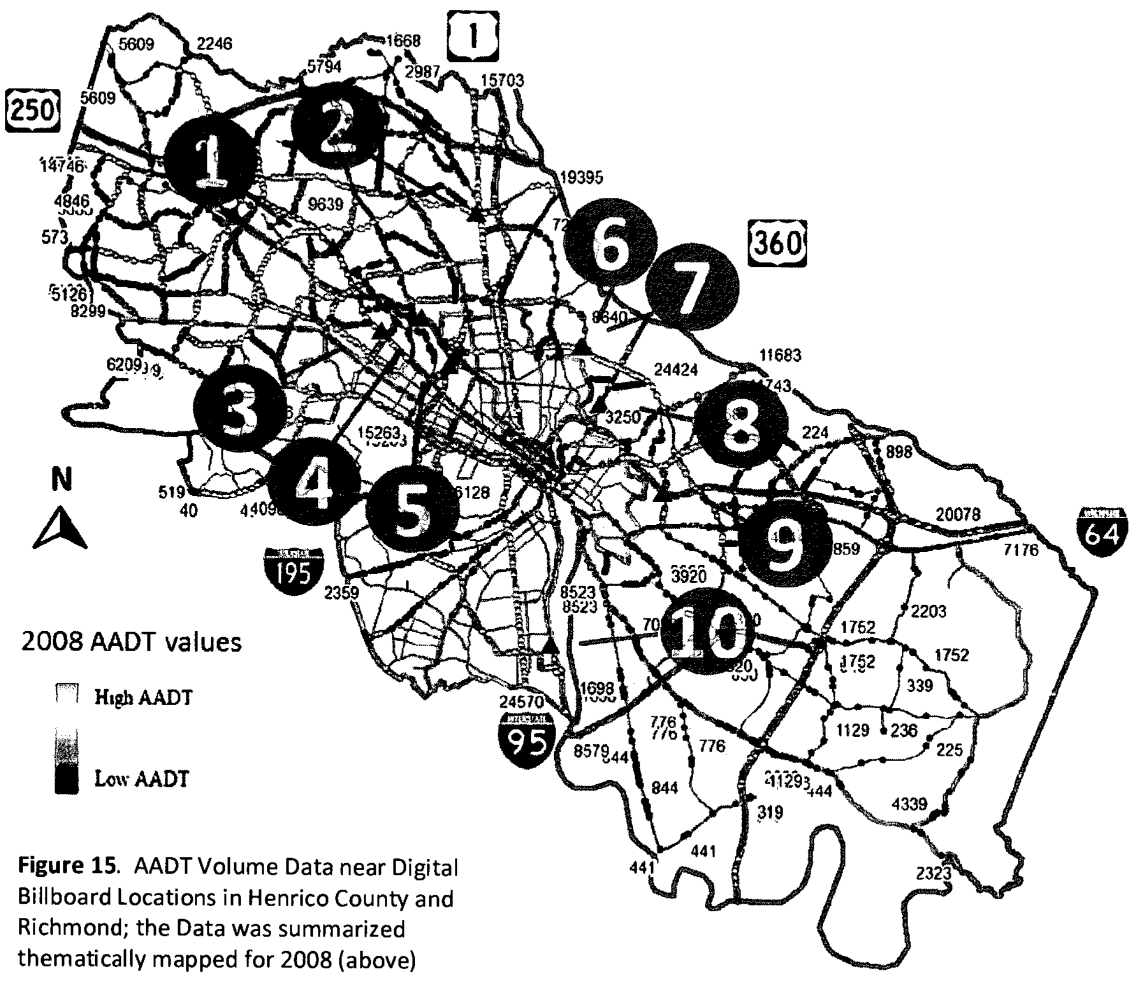


Figure 15. AADT Volume Data near Digital Billboard Locations in Henrico County and Richmond; the Data was summarized thematically mapped for 2008 (above)

ACCIDENT DATA

In this portion of the Greater Richmond Area, the majority of accident reports were investigated and recorded by each local and county Police Departments. Data were maintained by those Police Departments and compiled by the Virginia Department of Transportation. Law-enforcement officials are required to submit reports on crashes they investigate which meet reporting thresholds provided by statue, or in which someone was injured or killed. Data generally conform to the American National Standards Institute (ANSI) Standard D16.1 – 1996, Manual on Classification of Motor Vehicle Traffic Accidents.

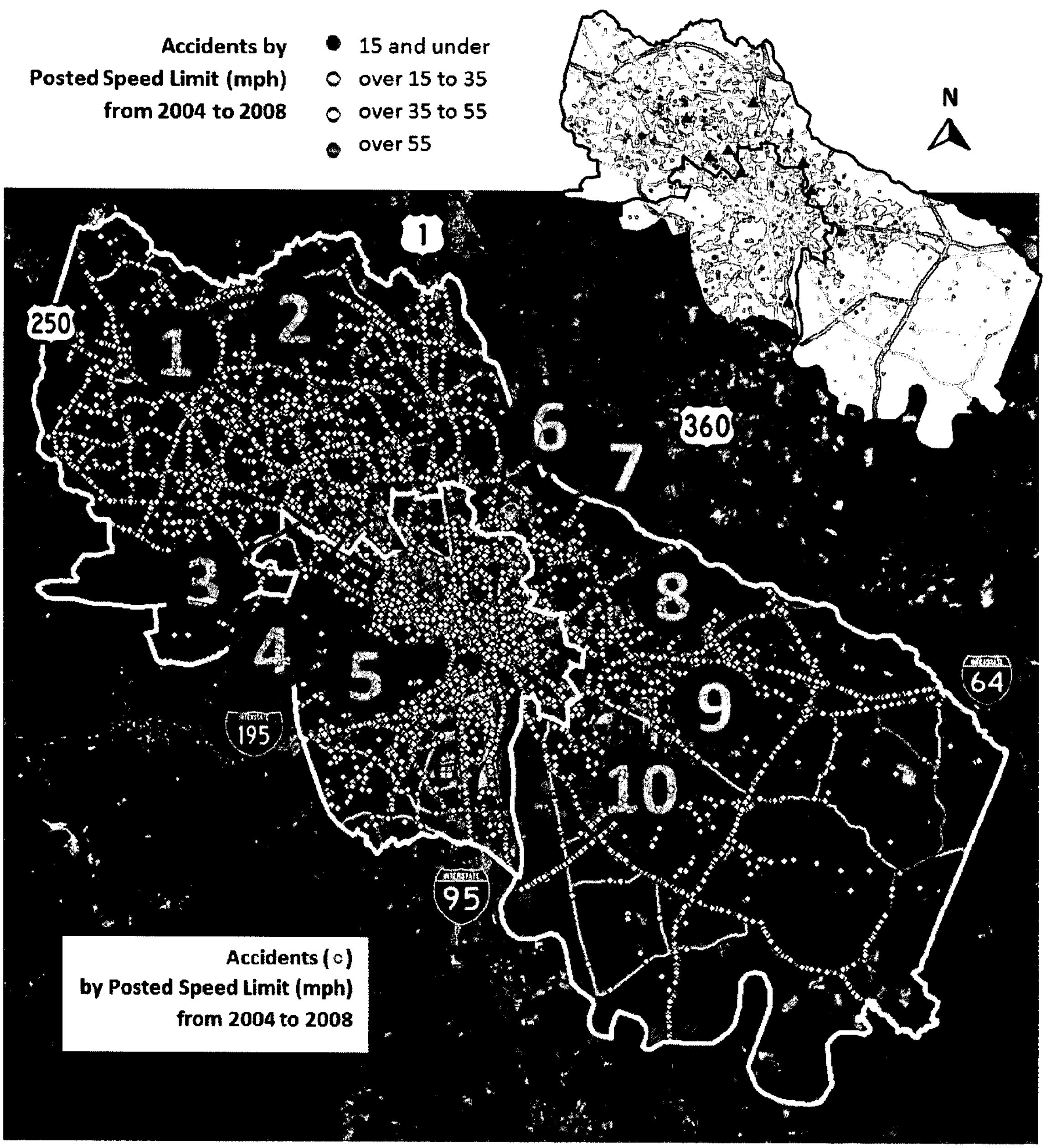


Figure 16. Traffic Accidents (yellow dots) near Digital Billboard Locations in Henrico County and Richmond, Virginia from 2004 to 2008; Inset shows Accident by Posted Speed Limit (mph)

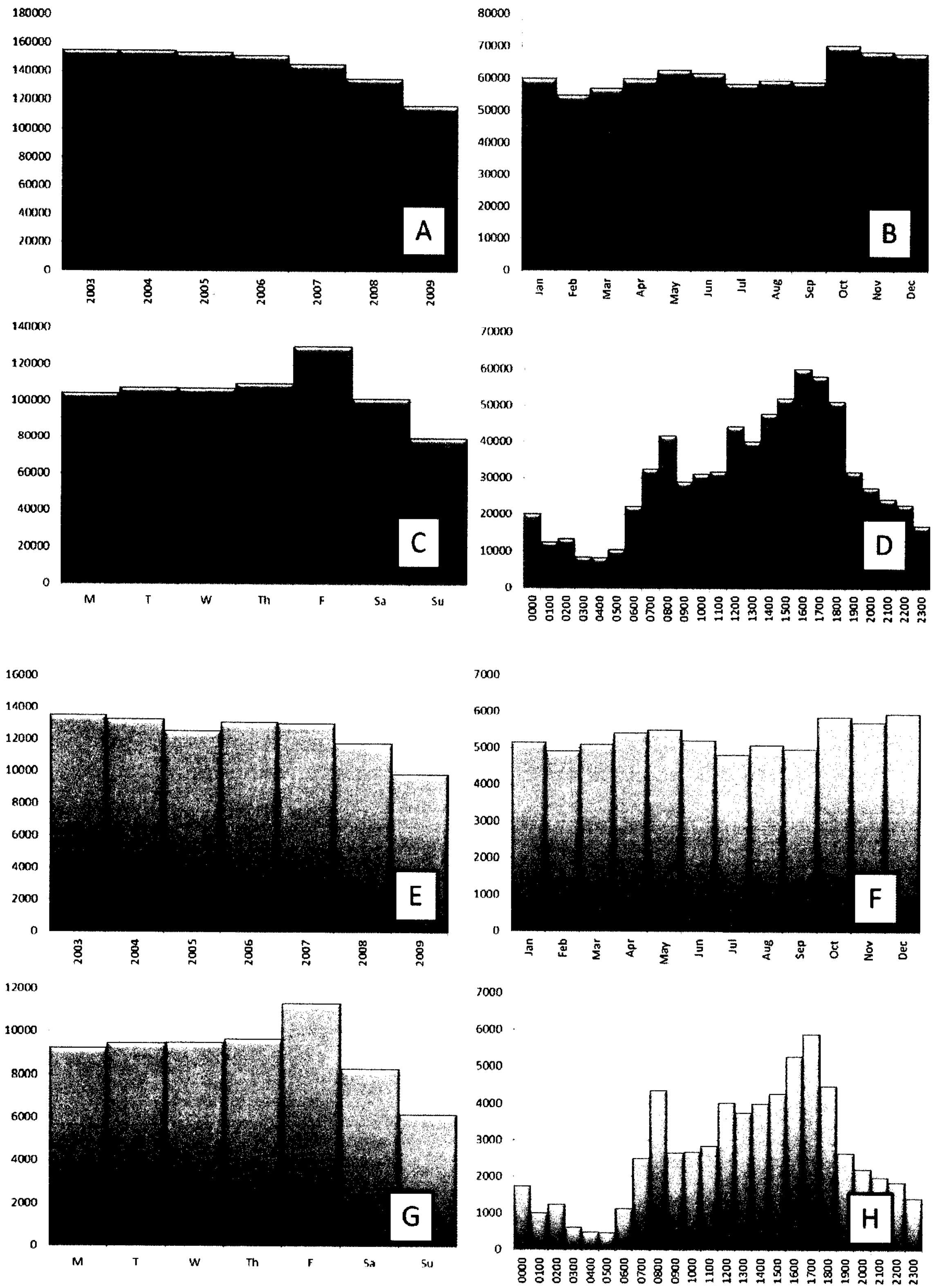


Figure 17. Histogram of Traffic Accident Data of the Past Seven Years in the State of Virginia (in blue) by Year (A), Month (B), Day of Week (C), and Time of Day (D) and in Henrico County and Richmond (in Red) by Year (E), Month (F), Day of Week (G), and Time of Day (H).

The analysis of this robust data involves an engineering-statistics based approach and uses widely accepted methods to show what happened when these 14 digital billboards faces were installed in Richmond.

The accident data-sets provided by VDOT include approximately 40,000 accidents during the seven years between 2004 and 2009 and near the digital billboard locations. Most of the data are specified by latitude and longitude or route nodes with offset distances. Figure 16 shows the geocoded accident locations generally within Henrico County and the City of Richmond.

Figure 17 summarizes the traffic accident data for the past seven years generally within the State of Virginia and within Henrico County and Richmond and show the distribution of accidents by year, month, day of week and time of day. This distribution represents a consistent pattern of data and illustrates that more accidents occur on weekdays and at rush hour (before and after work).

ANALYSIS

The analysis of this robust data involves an engineering-statistics based approach and uses widely accepted methods to show what happened when these 14 digital billboard faces were installed in Henrico County and Richmond.

The analysis has three parts.

Part 1 is a temporal analysis which compares *before* and *after* changes in crash rates and other metrics.

Part 2 is a spatial analysis which compares *where* and *how far* data to establish statistical correlation coefficients for various scenarios accounting for accident density and billboard proximity.

Part 3 uses the Empirical Bayes Method (EBM). This method uses the 'before' accident statistics to predict the number of accidents "expected" at the locations assuming that no digital billboard technology was introduced. The method is the basis of the safety analysis and science-based, predictive models introduced in the 2010 *Highway Safety Manual* of the American Association of State Highway Official (AASHTO, Reference 14). We quantify what the actual 'after' accident statistics are and compare them with what the predicted values are from the EB analysis. This method analyzes data from the ten billboard location and incorporates data using non-digital comparison sites.

Analysis: Part 1 – Temporal Comparisons

The first part is a temporal analysis. The incidence of traffic accidents near the digital billboards is examined for an equal length of time before and after the digital billboards were installed and activated. This part is for the purpose of establishing if traffic accidents occurred more or less frequently in the presence of these digital billboards. With information collected from police accident reports, the temporal analysis also uses metrics such as traffic volumes, the accident-rate values, the maximum number of accidents during any given month, etc.

For comparison, accident statistics were summarized near the digital billboards within multiple vicinity ranges of 0.2, 0.4, 0.6, 0.8, and 1.0 miles both upstream and downstream of each billboard. For locations on local roads, these vicinity ranges also sampled data to include: (1) accidents along the principal roads to which the digitals directly advertise, (2) accidents recorded as occurring within the intersection of the primary road and any cross roads, and (3) for crossroad accidents within a reasonable distance from the primary road to include drivers turning onto or leaving the primary road. Accident data for roads to which the digitals do not advertise or are not connected were excluded, even if they were within the specified vicinity range.

Analysis: Part 2 – Spatial Comparisons

The second part is a spatial analysis. This establishes statistical correlation coefficients between the digital billboards and accidents. Correlation coefficients are statistical measures of the "association" between two sets of data. The results are analyzed for various scenarios accounting for accident density and billboard proximity.

Additionally, subsets of accident data for age of driver and for daytime and nighttime accidents are analyzed for before and after comparisons. For a more lengthy discussion of analysis methods, please refer to previous studies (see References 3 and 4).

Analysis: Part 3 – The Empirical Bayes Method (EBM)

The third part of the analysis uses the Empirical Bays Method (EBM).

An Empirical Bayes Method (EBM) analysis is performed to estimate the number of accidents that could statistically be expected without the introduction of a digital sign.

Research literature suggests that the EBM method is appropriate for this type of analysis and is a widely accepted method in the field of traffic safety (see References 14 to 31). The method is the basis of the safety analysis and science-based, predictive models introduced within the 2010 *Highway Safety Manual* of the American Association of State Highway Official (AASHTO, Reference 14).

The negative binomial distribution is established by researchers as an accurate description of yearly crash variation between sites and was previously used to model and evaluate various transportation safety projects (see References 14 through 31). The correction for regression to the mean and the use of a negative binomial distribution are strengths of the EBM.

The EBM is used to estimate the number of crashes before the site change (i.e., before the introduction of digital technology). These "before" estimates are then used to predict the number of crashes that could be expected to occur at a certain location, during a specified year, without the introduction of digital technology.

The change in safety at a location is given as:

$$\Delta\, safety = B - A$$

where $\Delta\, safety$ is the change in the number of crashes, B is the expected number of crashes in the after period without the introduction of digital technology, and A is the actual number of crashes reported in the after period.

After identifying digital locations, a statistical crash estimate model (CEM) is developed. The CEM model is a multivariate, regression model used to estimate the mean and variance of the annual number of crashes that could be expected at each location. Various multivariate models were tested through an iterative process by fitting the available traits. The analysis uses a negative binomial distribution by fitting a generalized, linear model to the data by maximum likelihood estimation of the parameter vector, B.

The p-value is used as an indicator of the significance of the individual traits. The traits that produced a statistically sound model include the annual average daily traffic (AADT) for the location. The resulting CEM is then

$$P = \alpha_{\lambda}(AADT)^{\beta_1}\,(LANE)^{\beta_2}(Speed)^{\beta_3}.$$

The model parameters and the over-dispersion parameter (theta) are then calculated. The over-dispersion parameter is a measure of the extra variation in the negative binomial distributions compared to a traditional Poisson distribution; this parameter is commonly used in the calculation of the variance, or

$$variance = mean * \left(1 + \frac{mean}{\phi}\right).$$

Using the model, analyzed parameters and data, the expected number of crashes is estimated for each location, had no digital technology been introduced.

For each location, the first year for available data was used as a base year and a normalized mean number of crashes for each year, y is calculated as

$$C_y = \frac{P_y}{P_b}.$$

Where, P_y and P_b are the predicted total number of crashes from the CEM for the year y and the base year, respectively for each location. The projection of the number of crashes is independent of the choice of the base year.

The variance of the expected number of crashes, $Var(P)$ is calculated using the overdispersion parameter, as

$$Var(P) = (1 + \phi * P) * P.$$

The relative weight, α, is calculated as

$$\alpha = \frac{P}{Var(P)}.$$

Actual location crash counts, K, are then used to determine the EB estimate of mean and variance of the number of crashes for a site; EB and $Var(EB)$, respectively are

$$EB = \alpha * P + (1 - \alpha) * K, \text{ and}$$

$$Var(EB) = (1 - \alpha) * EB .$$

The projection of the expected "after" treatment number of crashes is based on the weighted average of the EB estimates of number of crashes of all "before" treatment years for conversion to digital technology.

The estimate of the baseline mean and the variance number of crashes, PC_b and $Var(PC_b)$ is determined as

$$PC_b = \frac{\sum_{before} EB}{\sum_{before} C_y}, \text{ and}$$

$$Var(PC_b) = \frac{\sum_{before} Var(EB)}{\left(\sum_{before} C_y\right)^2}.$$

The projected number of crashes for the conversion locations in the "after" conversion period is calculated by multiplying the normalized number of crashes/year, C_y, by the baseline projected number of crashes, PC_b. The mean and variance of the projected crash count in the "after" conversion period for year, y, B and $Var(B)$, are calculated as

$$B = C_y * PC_b, \text{ and}$$

$$Var(B) = C_y^2 * Var(PC_b).$$

The overall index of effectiveness, theta, is then calculated by comparing the total projected number of crashes (B) in the after period to the total actual number of crashes (A) in the after period as

$$\theta = \frac{\sum A}{\sum B}.$$

The unbiased estimate, θ_u, is then

$$\theta_u = \frac{\theta}{1+\frac{\sum Var(B)}{(\sum B)^2}}.$$

The percent change in total crashes due to the introduction of digital technology is

$$\Delta\, crashes\, (\%) = (1 - \theta_u) * 100.$$

If the change of introducing digital technology causes crashes to be increased, then θ_u will be significantly larger than one and $\Delta\, crashes$ will be a negative value significantly lower than zero.

This analysis is applied to the data at 66 locations representing the 10 digital locations and 56 comparison sites.

The number of accidents and rates of accidents near the ten digital billboards locations remained consistent within all vicinity ranges.

RESULTS

Figure 18 shows a comparison of the accident metrics for before and after conversions near all ten digital billboards in Henrico County and Richmond, Virginia. The statistics are summarized for vicinity ranges of 0.2, 0.4, 0.6, 0.8, and 1.0 miles of the digital locations with 10 -second duration times collectively. The metrics in Figure 18 include the total number of accidents, the average number of accidents in any given month, the peak number of accidents in any given month, etc. Other metrics, including rates and vehicle-miles traveled were also analyzed.

For all locations (Figure 18), the number of accidents and rates of accidents near the ten, digital billboards decreased in all vicinity ranges. The benchmark, 0.6-mile vicinity experienced a 4.5% decrease in the number of accidents over the seven year span for all location; this includes a 9.5% decrease in accident rates per hundred thousand AADT vehicles.

Figure 19 shows the distributions of the number of accidents per month near digital billboards within the benchmark 1.0 mile vicinity between 2003 and 2009.

A statistical t-test is used to determine whether the average difference between the two, time periods is really significant or if it is due to random difference. Using a 95% confidence interval indicates that no statistically significant difference in the accident statistics evaluated between conventional and digital billboards at these digital locations.

Additionally, consistent results were obtained for driver-age comparisons. Low correlation coefficients were calculated for this spatial analysis. Correlation coefficients were calculated and indicated a very strong correlation of accident patterns near the digital billboards when compared with the accident patterns prior to conversion.

The statistical evaluation of the Empirical Bayes Method and results show that the total number of accidents is approximately equivalent to what would be statistically expected with or without the introduction of digital technology and that the safety near these locations are consistent with the model benchmarked by 66 locations within Henrico County and Richmond.

Between 2003 and 2009 for equal periods before and after
At 10 locations in Henrico County and Richmond, Virginia
with 10 second duration times

		Vicinity Range from Digital Location (miles)				
		0.2	0.4	0.6	0.8	1.0
Prior to Installation	Total Number of Accidents for Equal Periods Before Conversion	241	649.75	832.25	1049.5	1243
Prior to Installation	Average Number of Accidents per Month at Each Location	1.02	2.75	3.53	4.45	5.27
Prior to Installation	Rate of Accidents per Vehicles (by hundred thousand AADT)	0.15	0.41	0.53	0.67	0.79
Prior to Installation	Standard Deviation of Number of Accidents in any given month	1.82	4.01	4.97	5.89	6.84
Prior to Installation	Peak Number of Accidents in any given Month per Location	11	19	26	28	35
Prior to Installation	Minimun Number of Accidents per Month per Location	0	0	0	0	0
Prior to Installation	Average Number of Accident-Free Months at Locations	52%	49%	40%	33%	33%
As Digital Location	Total Number of Accidents for Equal Periods After Conversion	205	617.25	795	977.25	1121
As Digital Location	Average Number of Accidents per Month at Each Location	0.89	2.67	3.44	4.23	4.85
As Digital Location	Rate of Accidents per Vehicles (by hundred thousand AADT)	0.12	0.37	0.48	0.59	0.68
As Digital Location	Standard Deviation of Number of Accidents in any given month	1.35	3.05	3.72	4.35	5.03
As Digital Location	Peak Number of Accidents in any given Month per Location	7.5	16	20	22	26.25
As Digital Location	Minimun Number of Accidents per Month per Location	0	0	0	0	0
As Digital Location	Average Number of Accident-Free Months at Locations	62%	52%	50%	42%	40%
Comparison	Change in Number of Accidents	-36	-32.5	-37.25	-72.25	-122
Comparison	Change in Average per Month	-0.13	-0.08	-0.08	-0.22	-0.41
Comparison	Change in Rate per vehicles (by hundred thousand AADT)	-0.03	-0.04	-0.05	-0.08	-0.12
Comparison	Percent Change in Number of Accidents	-14.9%	-5.0%	-4.5%	-6.9%	-9.8%
Comparison	Percent Change in Rate of Accidents	-19.4%	-10.0%	-9.5%	-11.8%	-14.6%

Figure 18. Summary of Accident Statistics within Vicinity Ranges near all Ten Digital-Billboards Locations with 10-second Duration Times in Henrico County and Richmond, Virginia

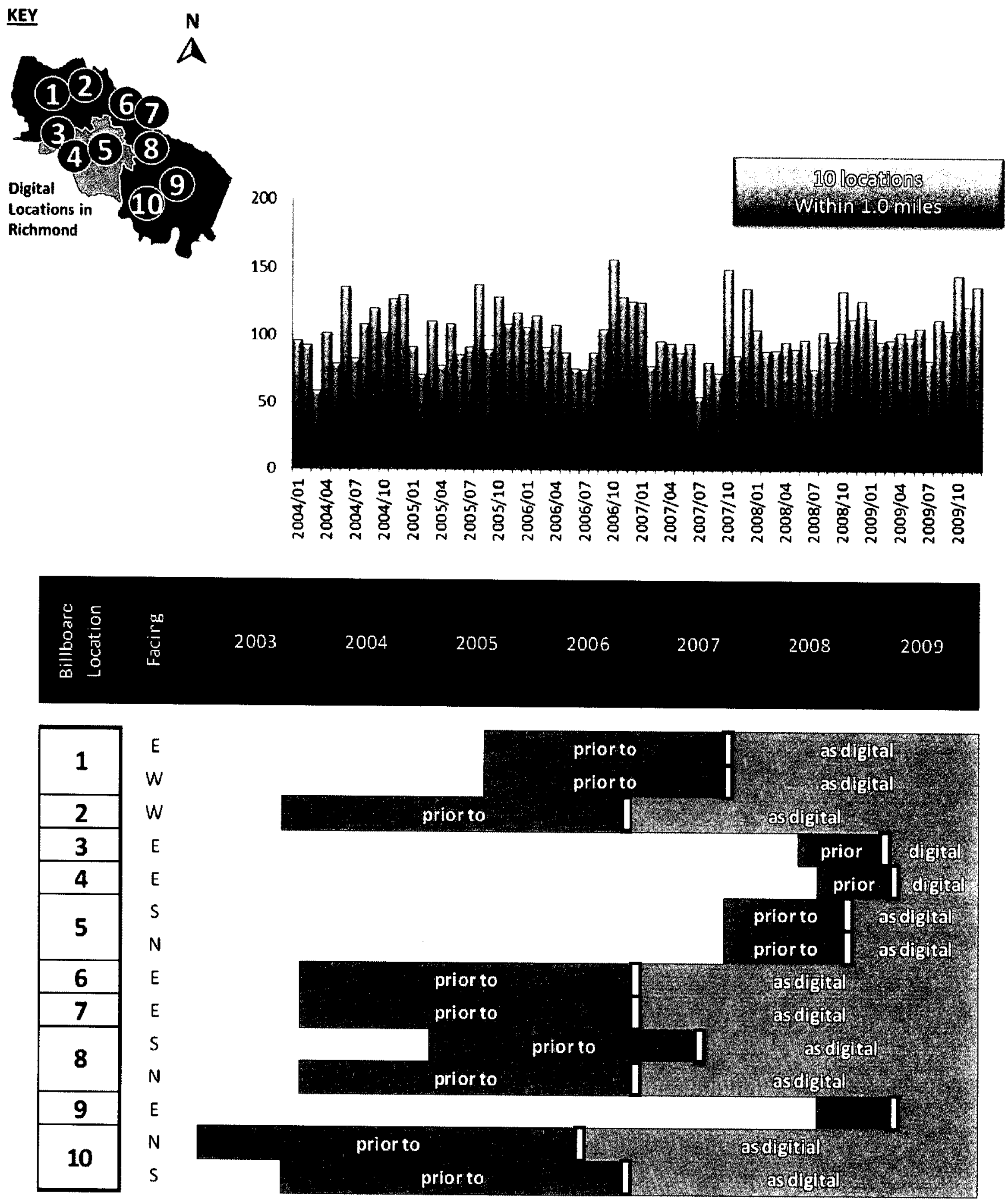


Figure 19. Distributions of the Number of Accidents per Month near Digital Billboards between 2004 and 2009, within a 1.0-mile Vicinity Range near all Digital Locations (top, red) compared with Conversion Dates and Before/After Comparison Periods

Figure 20 summarizes the accident rates that account for variations in traffic volumes for all digital locations within vicinity ranges of 0.2, 0.4, 0.6, 0.8, and 1.0 miles of the digital location. The 0.6 mile benchmark vicinity experienced a decrease in accident rates over the eight-year span. The change in accident rates decreased by 0.05 accidents per hundred thousand vehicles per year; a 9.5% decrease. Similar decreases and trends were observed for both smaller vicinity ranges.

Between 2003 and 2009 for equal periods before and after
At 10 locations in Henrico County and Richmond, Virginia
with 10 second duration times

		Vicinity Range from Digital Location (Miles)				
		0.2	0.4	0.6	0.8	1.0
Prior to Installation	Number of Accidents per million vehicles (by hundred thousand AADT)	0.15	0.41	0.53	0.67	0.79
As Digital Location	Number of Accidents per million vehicles (by hundred thousand AADT)	0.12	0.37	0.48	0.59	0.68
Comparison	Change in Rate per million vehicles (by hundred thousand AADT)	-0.03	-0.04	-0.05	-0.08	-0.12
Comparison	Percent Change in Rate of Accidents	-19.4%	-10.0%	-9.5%	-11.8%	-14.6%

Figure 20. Summary of Accident Rates within Vicinity Ranges near Ten Digital Billboards Locations 10- second-duration Times in Henrico County and Richmond, Virginia

COMPARISON OF ACCIDENTS BY AGE OF DRIVER

The accident statistics were also analyzed to determine if the age of the drivers involved in the accidents near the digital billboards was a factor. The data were specifically studied to determine if there are increases in the accident frequency of young drivers (under 17 and under 21) or elderly drivers (65 and older). Figure 21 summarizes the accidents and accident-rates by age of driver for all accidents.

Figure 22 shows the distributions of ages of driver for all accidents within Henrico County and Richmond (A, blue) and for all accidents within 1.0 miles of all digital locations (B, purple).

Figure 23 shows the distributions of driver ages within 1.0 miles of all digital locations for before (orange) and after (purple) periods of comparison. Figure 23 (left) also shows the correlation between before and after conversions for the number of accidents for each age. Individual accidents may have multiple cars and drivers involved, which is reflected in the analysis. In comparing the histograms in Figure 22 and 23, note the typical distribution type (shape) and typical average values. The mode driver age for accidents prior to digital conversion is 19 years; the mode drive age after conversions is 19 years.

Correlation coefficients were calculated and indicated a very strong correlation of accident patterns for age-of-driver factors. Figure 23 shows a 0.920 (92.0%) correlation coefficient when comparing accidents before conversion with those after conversion.

Between 2003 and 2009 for equal periods before and after
At 10 locations in Henrico County and Richmond, Virginia
with 10 second duration times

		Crashes By Driver Age Group			
		under 17	under 21	21-65	over 65
Prior to Installation	Number of Accidents for equal periods prior to conversion	6	134	1007	97
As Digital Location	Number of Accidents for equal periods after conversion	6	98	922	95
Comparison	Change in Number of Accidents	None	-36	85	2
	Percent Change in Number of Accidents	None	-26.9%	-8.4%	2.1%

Figure 21. Summary of Accidents by Age Group within Vicinity Ranges near Ten Digital Billboard Locations in Henrico County and Richmond, Virginia

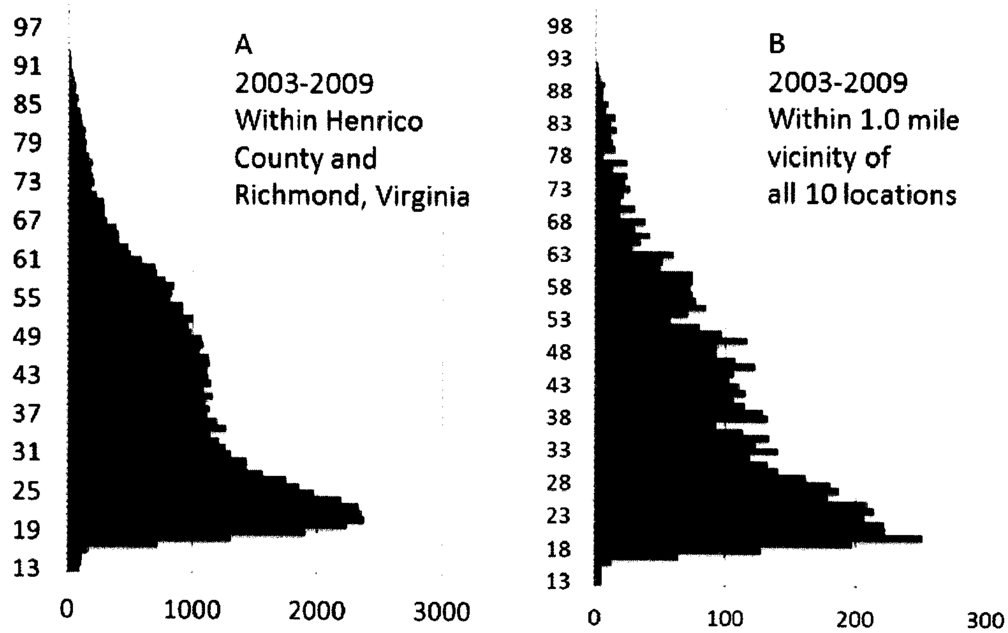


Figure 22. Distributions of Age of Drivers for all Accidents in the Henrico County and Richmond (left, blue), and within 1.0 miles of all Digital Locations (right, purple)

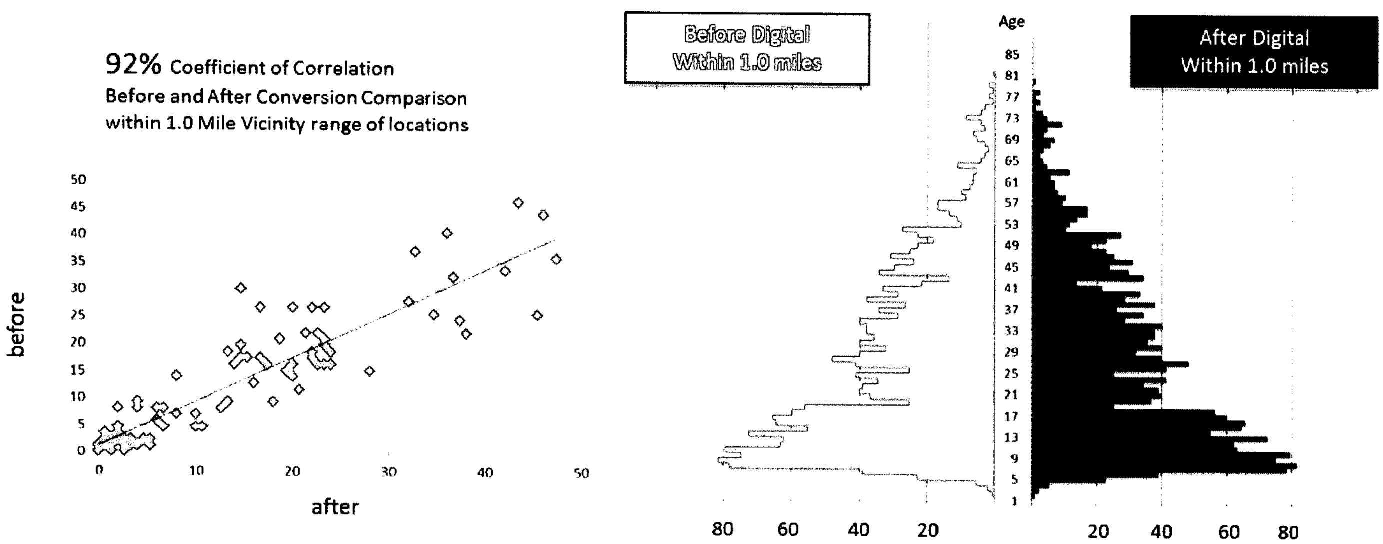


Figure 23. Distributions of Age of Drivers for all Accidents before Digital Conversion (left, orange histogram), after Digital Conversion (right, purple histogram) and the Correlation between Before and After Accident Counts for each Age (left).

COMPARISON OF ACCIDENTS BY TIME OF DAY

The accident statistics are also analyzed to determine if the time of day of the accidents near digital billboards is a factor.

The data are studied to determine if any increases in the accident rates during dawn, daylight, dusk and dark/nighttime conditions occurred. Figure 24 summarizes the accidents and accident-rates by time of day for all accidents within 1.0 miles of the digital locations. The daylight accident rate experienced a 15.5 percent decrease after conversion; the nighttime accident rate experienced a 4.7% decrease.

Figure 25 shows the distributions of times of accidents within 1.0 miles for before conversion (top, blue) and for after conversion (middle, red) data periods of comparison. Figure 25 (bottom) also shows the correlation between before and after conversions for the number of accidents. In comparing the histograms in Figure 25, note the typical distribution type (shape) and typical average values. Correlation coefficients were calculated and indicated a very strong correlation of accident patterns for time-of-day factors. Figure 25 shows a 0.90 (90.0%) correlation coefficient when comparing accidents before conversion with those after conversion.

Between 2003 and 2009 for equal periods before and after
At 10 locations in Henrico County and Richmond, Virginia
with 10 second duration times

		During Time of Day and Lighting			
		Dawn	Daylight	Dusk	Dark
Prior to Installation	Number of Accidents for equal periods prior to conversion	98	828	124	190
Prior to Installation	Number of Accidents per million vehicles (by hundred thousand AADT)	0.06	0.53	0.08	0.12
As Digital Location	Number of Accidents for equal periods after conversion	66	700	88	181
As Digital Location	Number of Accidents per million vehicles (by hundred thousand AADT)	0.04	0.42	0.05	0.11
Comparison	Change in Number of Accidents	-32	-128	-36	-9
Comparison	Change in Rate per million vehicles (by hundred thousand AADT)	-0.02	-0.11	-0.03	-0.01
Comparison	Percent Change in Number of Accidents	-32.7%	-15.5%	-29.0%	-4.7%
Comparison	Percent Change in Rate of Accidents	-36.2%	-19.9%	-32.8%	-9.8%

Figure 24. Summary of Accident Rates during Dawn, Daylight, Dusk and Dark/Nighttime Conditions within a 0.5 mile vicinity range near ten Digital Billboards Locations with 10-second-duration times in Henrico County and Richmond, Virginia

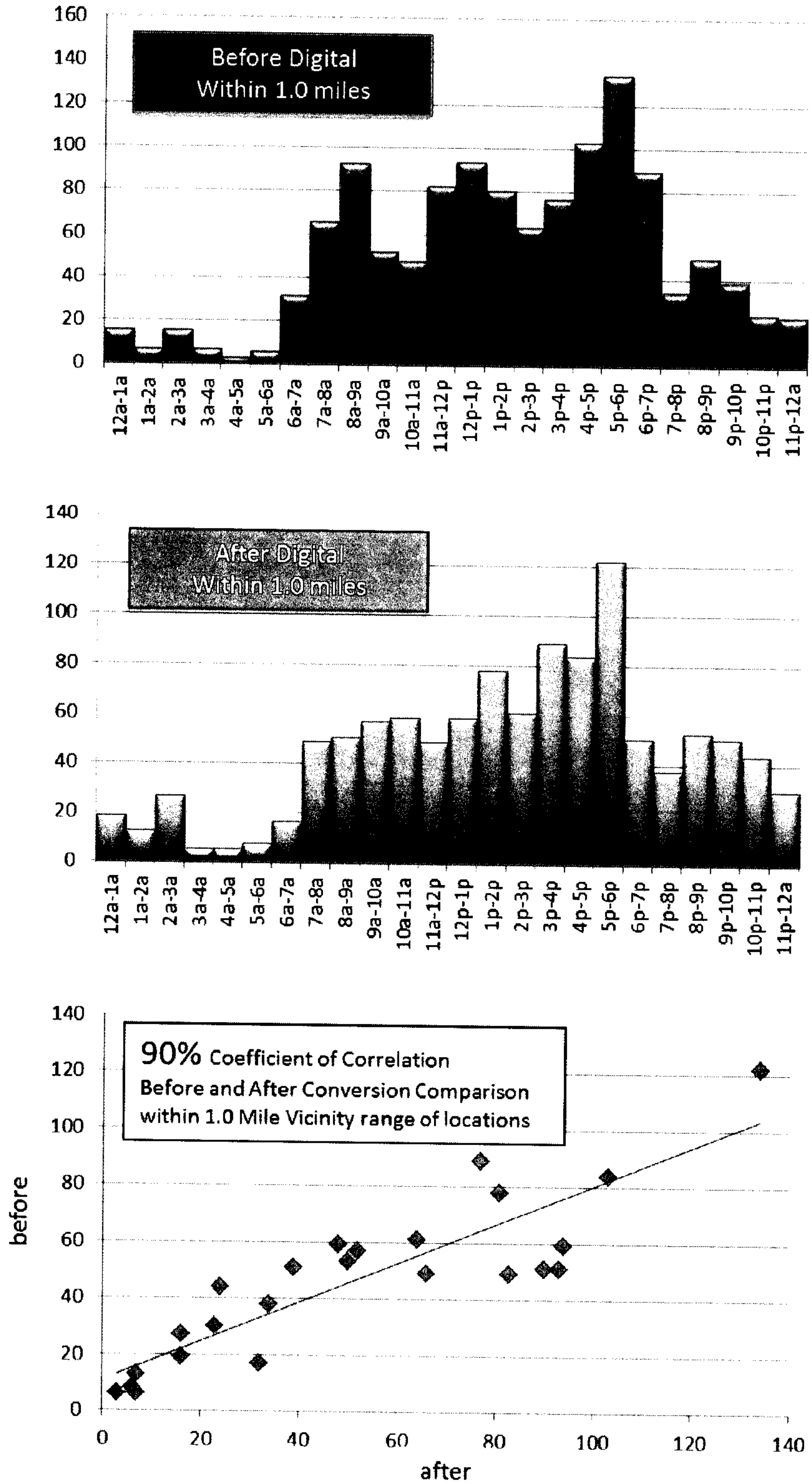


Figure 25. Distributions of Number of Accidents Accident by Time of Day within a 1.0 mile Vicinity Range prior to Digital Conversion (top, blue) and after digital conversion (middle, red) near ten digital billboards locations with 10- second-duration times in Henrico County and Richmond, Virginia

STATISTICAL MODEL AND RESULTS FOR THE EMPIRICAL BAYES METHOD

The Empirical Bayes Method (EBM) is used to analyze available crash data in Henrico County and Richmond, Virginia. The EBM method is a rigorous method capable of estimating the safety impact of changes at a location. The EBM method is well documented and used in numerous traffic-safety studies (see References 14 through 31). Simply stated, the method estimates the number of crashes at a location that would have occurred without the introduction of digital billboards. The estimates may then be compared with the actual crashes that have occurred.

The expected number of crashes as estimated by the Crash Estimation Model (CEM) and using the SAS statistical package and the parameters discussed in our methodology were computed. A multivariate, regression model was developed to estimate the mean of the expected number of crashes at a location. Our general CEM is shown in Figure 26 and models Average Annual Daily Traffic (AADT), Number of Lanes (Lane), and the posted Speed Limit (Speed) as independent variables; β_0, β_1, β_2, and β_3 are model parameters of the independent variables. The model is fit using the maximum likelihood method and includes 90 sites representing 10 digital billboard locations and 80 comparison sites. Figure 27 shows these locations. Figure 26 summarizes the CEM parameters using a maximum likelihood estimates for a multivariate regression model with negative binomial distribution. The CEM parameters are significant at $\alpha = 0.05$. The resulting CEM equation is also presented in Figure 26.

The projected, total crash counts were estimated for the "after" periods to represent what the number of crashes would have been in future period without the introduction of digital billboards. These were compared with the crash data that actually occurred after the introduction of digital billboards at each location to determine the overall index of effectiveness.

General CEM: $$P = (AADT)^{\beta_1}\, (LANE)^{\beta_2} (Speed)^{\beta_3}\, e^{\beta_0}$$

Explicit CEM: $$P = (AADT)^{.0285}\, (LANE)^{0.1381} (Speed)^{-0.0070}\, e^{2.7599}$$

CEM Model Parameters:

Variable		Coefficient	Standard Error	Chi-square statistic	Pr > Chi-square	Wald 90% confidence limits	
						Lower	Upper
Intercept		2.7599	0.1943	201.81	<.0001	2.3792	3.1407
AADT	β_1	0.0285	0.0020	205.35	<.0001	0.0246	0.0324
lanes	β_2	0.1381	0.0293	22.25	<.0001	0.0807	0.1955
speed	β_3	-0.0070	0.0022	10.45	0.0012	-0.0112	-0.0027
Dispersion	ϕ	0.4445	0.0325			0.3808	0.5081

SAS Goodness of fit measures: deviance (value/d.f.) = 438.3687 (1.1014); Pearson chi-square (value/d.f.) = 373.611 (0.9387); Number of observations = 680

Figure 26. General and Explicit Crash Estimation Model (CEM) and CEM Model Parameters from SAS Output

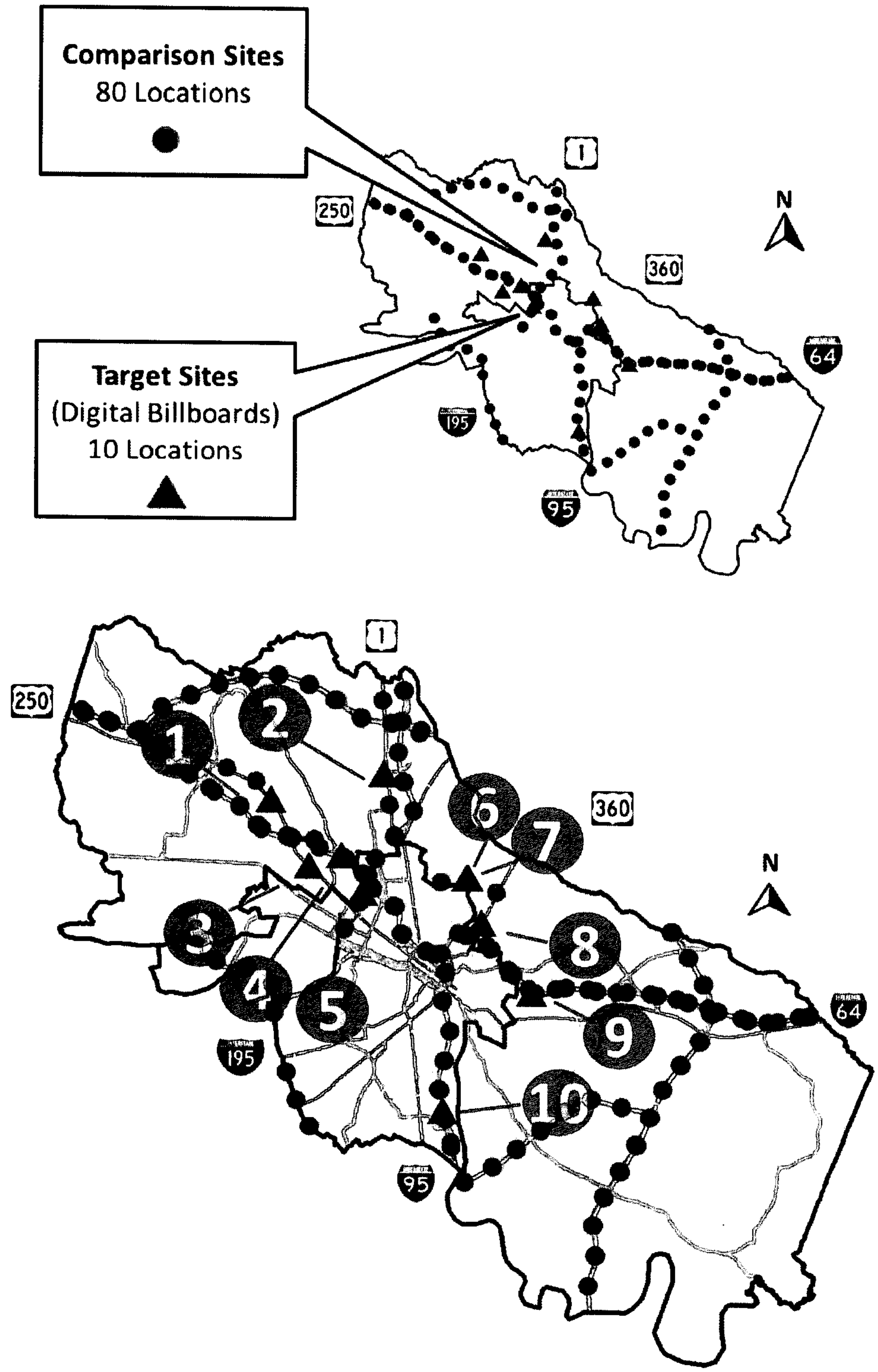


Figure 27. Crash and AADT Data for 10 Target (Digital) Locations and 80 Comparison (non-Digital) Locations

The Empirical Bayes Method results indicate a 0.0142 (1.42%) difference between the "after" conversion crashes that occurred near the 10 digital locations and the statistically predicted Empirical Bayes mean estimate of those same locations had no digital billboards been installed. This comparison has a p-value less than 0.0001. The analysis of this data indicates that the actual and predicted means are almost statistically consistent. A large sample size was used with 10 digital locations, 80 treatment or comparison sites with seven years of accident data. The statistical evaluation of the Empirical Bayes Method analysis shows that the total number of accidents is slightly less than what would be statistically expected with or without the introduction of digital technology and that the safety near these locations are consistent with the model benchmarked by 90 locations within Henrico County and Richmond, Virginia. Additional studies should be considered with other independent variables, consider for lower volume roads, other robust crash estimation models, and cross-comparison of results between digital.

Parameter	**Value**
Total Crashes for the "After" Period with Digital Conversion (Actual Values)	1121
Total Crashes for the "After" Period assuming no Digital Conversion ever occurred (Estimate by Empirical Bayes Method)	1137
Overall Index of Effectiveness	0.986
Percent Change in Crashes between actual and estimate	1.42%

Figure 28. Results of the Empirical Bayes Method Estimation in Henrico County and Richmond, Virginia with 10 digital locations, 80 Treatment or Comparison Sites and with Seven Years of Accident Data

Simply stated, the data show no statistically significant increase of accident rates near these billboards.

FINDINGS

Henrico County and Richmond, Virginia are a unique opportunity for this study about the statistical associations between digital billboards and traffic safety using robust data-sets and analyzing multiple locations for periods of more than seven years. The overall conclusion is that these digital billboards in Richmond have no statistically significant relationship with the occurrence of accidents. This conclusion is based on local Police and VDOT data and an objective statistical analysis; the data show no statistically significant increase in accident rates. This study also finds that **the age of the driver (younger, older)** and **the time of day (nighttime, daytime) are neutral factors** which show no increase in accident rates near these digital billboards along the routes in in Henrico County and Richmond, Virginia.

The specific conclusions of this study indicate the following.

• **The before and after rates of accidents near the 10 digital billboard locations show decreases** within 1.0 miles of all digital billboards for more than seven years. Similar decreases and trends in both averages and peaks are observed for smaller vicinity ranges.

• **The accident statistics and metrics remain consistent**, exhibiting statistically insignificant variations at each of the digital billboards. The metrics include the total number of accidents in any given month, the average number of accidents, the peak number of accidents in any given month, and the number of accident-free months. These conclusions account for variations in traffic-volume and other metrics.

• The statistical evaluation of the Empirical Bayes Method and actual versus predicted results, show that the **total number of accidents is consistent with what would be statistically expected with or without the introduction of digital technology** and that the safety near this locations are consistent with the model benchmarked by 90 locations within and near Richmond Virginia.

• The overall conclusion of the study is that **these digital billboards in Richmond have no statistically significant relationship with the occurrence of accidents**.

This study also finds that the age of drivers (younger/elderly) and the time of day (daytime/nighttime) are neutral factors which show no significant increase in accident rates near the digital billboards. These conclusions are based on the collected Police Department data and on an objective statistical analysis.

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