Lag Acceptance Analysis for a Rural Unsignalized Intersection

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ABSTRACT

More than 30% of all vehicle crashes in the US occur at intersections; these crashes result in nearly 9000 annual fatalities, or approximately 25% of all traffic fatalities. Moreover, these crashes lead to approximately 1.5 M annual injuries, accounting for approximately 50% of all traffic injuries. AASHTO recognized the significance of rural unsignalized intersection crashes in its 2005 Strategic Highway Safety Plan, and identified the development and use of new technologies as a key initiative to address the problem of intersection crashes.

Before a new technology to reduce intersection crashes can be deployed, driver behavior leading to these crashed must be better understood. Described herein are lag acceptance distributions measured by a traffic surveillance system which measures and records the state of the intersection at 10 Hz. Sensitivity of accepted lag distributions to traffic density, time of day, and time waiting for a lag is described. An understanding of these lag acceptance distributions can be used as the basis for the timing of the alerts and warnings issued to drivers waiting to enter or cross the major road traffic stream.

Comparisons of lag acceptance at the test intersection to critical gaps and gaps in major-road traffic implied by current AASHTO policy to be acceptable are provided. Distributions of lags accepted at the intersection show that a significant number of drivers accept lags smaller than those described by critical gap methods and AASHTO policy. An analysis of these smaller than expected lags are also presented.

INTRODUCTION

Motivation

More than 40% of all police reported crashes in the US occur at intersections; these crashes result in nearly 9000 annual fatalities, or approximately 25% of all traffic fatalities. Of these intersection fatalities, nearly 70% occur at unsignalized intersections. Moreover, these intersection crashes lead to approximately 1.5 M annual injuries, accounting for approximately 50% of all traffic injuries.

AASHTO recognized the significance of unsignalized intersection crashes in its 2005 Strategic Highway Safety Plan (1), and identified the development and use of new technologies as a key initiative to address the problem of intersection crashes in (2). Objective 17.1.4: “Assist drivers in judging gap sizes at Unsignalized Intersections.”

To clearly define the rural intersection crash problem, an extensive review of both the Minnesota Crash Database and research reports quantifying the national problem was undertaken; the results are documented in (3). This study of 3,700 Minnesota intersections shows that crashes at rural expressway thru-STOP intersections have similar crash and severity rates when compared to all rural thru-STOP intersections. Right angle crashes (which are most often related to improper lag selection) were observed to account for 36 percent of all crashes at these rural expressway intersections. At rural expressway intersections that have higher than expected crash rates, approximately 50 percent of the crashes are right angle crashes. Further investigation also found that drivers’ inability to recognize the intersection, and consequently run the STOP sign, was cause for only a small fraction of right angle crashes. Poor lag selection is the predominate problem. It is important to note that not seeing or not recognizing the presence of an approaching vehicle represents a lag acceptance problem.

The notion that lag selection is the predominate problem is consistent with other findings; Chovan et al. (4) found that the primary causal factors for drivers who stopped before entering the intersection were:

1. The driver looked but did not see the other vehicle (62.1 %),
2. The driver misjudged the lag size or velocity of the approaching vehicles (19.6 %),
3. The driver had an obstructed view (14.0 %), or
4. The roads were ice-covered (4.4 %).
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Of these four driver errors, the first three can be described as either problems with lag detection or lag selection.

Recent crash analyses, including field visits and crash database reviews, for Michigan (6), North Carolina (7), and Wisconsin (2) have shown that in these states, poor lag acceptance on the part of the driver is the primary causal factor in approximately 60% of rural thru-Stop, right-angle intersection crashes.

Understanding driver gap acceptance.

To address the problem of poor lag selection, the University of Minnesota and the Minnesota Department of Transportation (Mn/DOT), under the FHWA Cooperative Intersection Collision Avoidance System-Stop Sign Assist (CICAS-SSA) program, are designing a system to alert drivers to dangerous conditions and warn them when it is unsafe to enter the intersection. The system consists of two fundamental subsystems: (a) the sensor system, which computes the “state” of the intersection, including the position, speed, and lane of travel of all vehicles on the major roads, and the location and size classification of vehicles on the minor road, and (b) a driver interface system, which assesses the threat to a driver on the minor road, computes alerts and warnings, and displays relevant information to a driver via a dynamic sign located at the intersection.

Key to the success of the CICAS-SSA program will be the ability of the system to issue alerts and warnings at the proper time to the driver. Alerts provided prematurely will create credibility problems because the driver will view the system as too conservative, and therefore unacceptable; alerts provided too late will do little to reduce crashes as a driver may have departed the minor road before the warning or alert was activated.

Before an effective rural intersection crash countermeasure can be designed and deployed, driver behavior at rural unsignalized intersections must be better understood. The purpose of the work describe herein is to determine the distribution of lags accepted at a rural, thru-stop expressway intersection as the critical first step needed to determine the proper timing for alerts and warnings provided to a driver attempting to enter or cross major road traffic from the minor road. Sensitivity of accepted lag distributions to traffic density, time of day, and time waiting for a lag is also explored; high sensitivity to variations in these parameters will affect alert and warning timing.

To collect the data needed to determine the distribution of accepted gaps at a thru-stop rural expressway intersection, a comprehensive rural intersection surveillance system has been designed and built at the intersection of US 52 and County State Aid Highway 9 (CSAH 9) in Goodhue County, MN, under sponsorship of the US DOT Intersection Decision Support (IDS) program (8). The surveillance system uses sensors, computer processors, a communication network, and a geometric representation of the roadways to determine the “state” of the intersection. Mainline state information includes the position, speed, (derived) acceleration, and lane of travel of each vehicle within the surveillance zone. This state information, combined with known intersection geometry, facilitates the real time tracking of traffic gaps on the mainline. Minor road state information includes the position and speed of the vehicle on the minor road, and an estimate of the classification of the vehicle. Present classification separates vehicles into four categories:

* Group 1: Motorcycles, sedans and small SUVs (Class 1 and 2),
* Group 2: Large SUVs and pickup trucks (Class 3),
* Group 3: Single-unit trucks (Class 4 – Class 6), and
* Group 4: Semi-trucks and other large vehicles (Class 7 and higher)

A central processor computes the “state” of the intersection at 10 Hz.

Although a number of studies have been undertaken to characterize gap and lag acceptance behavior exhibited by drivers (9)-(13), these studies were based on relatively short observation times, and did not benefit from a comprehensive surveillance system. This paper presents analysis results from data collected during 01 February 2005 – 15 April 2005. Using these results and additional data to be collected in other states a system, including a driver interface, which will support lag and gap acceptance decisions will be designed and tested under the auspices of the CICAS-SSA program.
LAG ACCEPTANCE ANALYSIS

Background
A significant body of work dealing with gap and lag acceptance has been produced, with (14) and (15) notable NCHRP and AASHTO works, respectively. TABLE 1 below summarizes the “time gap at design speeds of major roads” for left turn, right turns, and straight-through maneuvers, as reported in (15). Note that even within (15), discrepancies exist between time gaps for right turns exist (highlighted by italics). Clearly, warning and alert timing cannot be based on these numbers alone; a distribution of lag acceptance times are needed to properly time warnings.

TABLE 1. Time gaps for stop controlled intersections taken from (15). Note that even within (15), discrepancies existing as to what dictates an acceptable time gap. Variation of this value demonstrates uncertainty determining an acceptable gap. Notion of “critical gap” adds to the uncertainty.

<table>
<thead>
<tr>
<th>Design Vehicle</th>
<th>Time gap(s) at design speed of major road for a stopped vehicle to turn right or left onto a two-lane highway with no median and grades of 3% or less.</th>
<th>Time gap(s) at design speed of major road for a stopped vehicle to turn right onto or cross a two-lane highway with no median and grades of 3% or less.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passenger car</td>
<td>7.5 s</td>
<td>6.5 s</td>
</tr>
<tr>
<td>Single-unit truck</td>
<td>9.5 s</td>
<td>8.5 s</td>
</tr>
<tr>
<td>Combination truck</td>
<td>11.5 s</td>
<td>10.5 s</td>
</tr>
</tbody>
</table>

Adjustments
Multilane Highways: for left turns onto two-way highways with more than 2 lanes, add 0.5 seconds for passengers cars, and 0.7 seconds for trucks for each additional lane, from the left, in excess of one, to be cross by the turn vehicle. Multilane Highways: for left turns onto two-way highways with more than 2 lanes, add 0.5 seconds for passengers cars, and 0.7 seconds for trucks for each additional lane to be crossed and for narrow medians which cannot store the design vehicle

In this paper, the definition of “lag” is tied to intersection geometry. Using a geometric reference from which to measure lag acceptance ensures consistency throughout the analysis, and minimizes discrepancies associated with sensor readings, rolling stops, “inching” forward, etc. Associating lag acceptance with intersection geometry leads to an objective measurement; this is in contract to human observers equipped with stop watches who subjectively determine when a driver begins entering or crossing a traffic stream. FIGURE 1 illustrates the test intersection geometry and its associated regions.

Differences between “gap” and “lag” should be clarified. In (14), a gap is defined “as the time headway between to vehicles on the major road,” and a lag is defined as the “portion of the gap which remains when the minor road vehicle first arrives at the stop line or begins to move onto the major road.” In the sequel, only lags are considered.

TABLE 2 lists the vehicle trajectories of interest; some trajectories require twolag acceptance decisions. The column “Region 1” lists the region which the minor road vehicle has to vacate for the first maneuver; column “Region 2” lists the region vacated for the second maneuver. Because of initial restrictions placed on the locations of sensors for the surveillance system, the sensor geometry used to measure vehicle trajectories makes determination of the time at which a vehicle arrives at a stop line or begins to move onto the major road difficult to measure precisely. However, the time at which a vehicle vacates a specific intersection region is reliably measured. Herein, lag is defined as the time it would take a mainline vehicle to reach the center of the crossroads (indicated in FIGURE 1 by stars) if its speed and acceleration were held constant at the time the minor road vehicle vacated one of the stop regions highlighted in FIGURE 1.

Geometric limitations on the location of sensors imposed previously at these rural intersections have been overcome; the Minnesota Mobile Intersection Surveillance System described in (16) is able to determine with higher accuracy when a vehicle begins to move from the stop bar or when it enters a specific intersection geometric region. This improved capability produces lag measurements more aligned with traditional definitions.
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A danger exists when trying to “match” or temporally align accepted lag values computed herein using a geometric lag definition to those accepted gap times recorded by human observers and subsequently reported in (14) and (15). The measures and techniques are simply too disparate. Instead, the objective is to characterize the distribution of the lags accepted by the drivers, and to determine sensitivities to parameters including time of day, traffic density, and time spent waiting for an acceptable lag. Once the distributions and sensitivities are understood, initial warning and alert timing can be determined. It is likely that the initial values will be adjusted over the course of time, but a basis for these values can be established early on, independent of subjective measures.

That being stated, the AASHTO time gaps listed in Table A, Column 2 for left turns, and Table A, Column 3 for passenger cars are used for right turns and straight-thrus, are provided in TABLE 2 below to be used as a reference. Median accepted lag times reported in this paper will generally be shorter than those listed in (14) and (15) because of the definition, but how much shorter is difficult to ascertain.

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**FIGURE 1.** Plan view of crossroads of US 52 and CSAH 9. Small rectangles represent the regions a vehicle must clear before the lag calculation begins. Stars indicate the reference used for the computation of the lag to the vehicles on the major road. Stop bars are indicated as shown. Zones, identified by dashed rectangles, represent groups of regions used to identify the maneuvers described in (15) during database queries. Zones 1 & 2 represent maneuvers from the stop bar, and zones 7 & 8 represent maneuvers from the crossroads median.
TABLE 2: Maneuver categories for US 52 and Goodhue County Road 9. Region 1 and Region 2, respectively, represent the starting point of each sub-maneuver. AASHTO Gap times for Passenger cars are provided for reference only; for right turns, the smaller AASHTO number is used. (“Strt” represents straight-thru, “LT” represents a left turn, and “RT” represents a right turn.)

<table>
<thead>
<tr>
<th>Maneuver</th>
<th>Maneuver ID</th>
<th>Sub-maneuvers (1,2)</th>
<th>AASHTO Gap Time, Sub-maneuver 1, for passenger cars, s</th>
<th>Region 1</th>
<th>Region 2</th>
<th>AASHTO Gap Time, sub-maneuver 2, for passenger cars, s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cty 9E to Cty 9E</td>
<td>1</td>
<td>Strt, Strt</td>
<td>6.5</td>
<td>2584</td>
<td>2576</td>
<td>6.5</td>
</tr>
<tr>
<td>Cty 9W to Cty 9W</td>
<td>2</td>
<td>Strt, Strt</td>
<td>6.5</td>
<td>113</td>
<td>106</td>
<td>6.5</td>
</tr>
<tr>
<td>Cty 9E to US 52N</td>
<td>3</td>
<td>Strt, LT</td>
<td>6.5</td>
<td>2584</td>
<td>2576</td>
<td>7.5</td>
</tr>
<tr>
<td>Cty 9W to US 52S</td>
<td>4</td>
<td>Strt, LT</td>
<td>6.5</td>
<td>113</td>
<td>106</td>
<td>7.5</td>
</tr>
<tr>
<td>Cty 9W to US 52N</td>
<td>5</td>
<td>RT</td>
<td>6.5</td>
<td>27504</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Cty 9E to US 52S</td>
<td>6</td>
<td>RT</td>
<td>6.5</td>
<td>25005</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>US 52S to US 52N</td>
<td>7</td>
<td>LT</td>
<td>7.5</td>
<td>2576</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>US 52N to US 52S</td>
<td>8</td>
<td>LT</td>
<td>7.5</td>
<td>106</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>US 52S to Cty 9E</td>
<td>9</td>
<td>LT</td>
<td>7.5</td>
<td>2576</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>US 52N to Cty 9W</td>
<td>10</td>
<td>LT</td>
<td>7.5</td>
<td>106</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Accepted Lag Analyses

Four lag analyses are presented: time of day/traffic volume, vehicle classification, accepted gap as a function of time waiting at the stop bar and at the median, and small accepted lags.

Drivers on either leg of CSAH 9 make few left turns. Near CSAH 9, US 52 bears 46 degrees west. Northbound travelers departing west of US 52 will take county roads directly north to US 52. Likewise, southbound travelers departing east of US 52 will take county roads south directly to US 52. Approximately 100 right turns and 100 straight-thrus occur for every left turn. Because of space constraints and a relatively low sample size, only right turns and straight-thrus are addressed below.

Time of day effects/traffic volume effects

The first analysis examines the relationship between time of day/traffic volume and lag acceptance. The primary question is whether traffic volumes are correlated with accepted lags. The hypothesis is that with heavier mainline traffic, only smaller, less frequent lags are available to the driver on the minor road. If a driver wants to proceed in a timely fashion, he or she is forced to accept smaller lags.

FIGURE 2 and TABLE 3 show lags as a function of maneuver and time of day. The selection of lags appears relatively insensitive to the traffic volume. Comparison of the median values for accepted lag in TABLE 3 for both straight-thrus and right turns shows a variation in the median accepted lag of less than 15%. The correlation is weak, indicating that gap acceptance is relatively insensitive to traffic volumes at this location.
FIGURE 2. Lognormal lag acceptance distributions for straight-thru and right turn accepted lags as a function of time traffic volume. Red lines differentiate small, medium, and high traffic volumes on the vehicle count averages plot. The correlation between time of day and traffic volumes is quite strong.
TABLE 3. Statistics for accepted lags as a function of traffic volume. Note that the medians of the lognormal distributions change less than 15% for both right turns and straight-thru maneuvers, indicating weak correlation between traffic volume and accepted lags. The variation in variance, on the other hand, is more substantial.

<table>
<thead>
<tr>
<th>Right turn/ Strght thru</th>
<th>Traffic Density</th>
<th>Total Lags</th>
<th>Mu</th>
<th>Median, $e^\mu$ - offset (s)</th>
<th>Sigma</th>
<th>Offset (s)</th>
<th>Residual</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rt. Turn</td>
<td>Low</td>
<td>447</td>
<td>2.00</td>
<td>11.37</td>
<td>1.77</td>
<td>-4.02</td>
<td>0.056</td>
</tr>
<tr>
<td>Rt. Turn</td>
<td>Medium</td>
<td>2786</td>
<td>2.18</td>
<td>10.79</td>
<td>0.86</td>
<td>-1.97</td>
<td>0.025</td>
</tr>
<tr>
<td>Rt. Turn</td>
<td>High</td>
<td>1853</td>
<td>2.07</td>
<td>9.71</td>
<td>1.01</td>
<td>-1.81</td>
<td>0.024</td>
</tr>
<tr>
<td>Strght – Thru</td>
<td>Low</td>
<td>641</td>
<td>1.95</td>
<td>8.81</td>
<td>1.51</td>
<td>-1.82</td>
<td>0.033</td>
</tr>
<tr>
<td>Strght – Thru</td>
<td>Medium</td>
<td>4518</td>
<td>1.92</td>
<td>8.53</td>
<td>0.76</td>
<td>-1.68</td>
<td>0.007</td>
</tr>
<tr>
<td>Strght – Thru</td>
<td>High</td>
<td>3696</td>
<td>1.84</td>
<td>7.96</td>
<td>0.82</td>
<td>-1.69</td>
<td>0.014</td>
</tr>
</tbody>
</table>

**Vehicle classification effects.**

FIGURE 3 and TABLE 4 show the accepted lag distributions and statistics, respectively. The numbers for all four vehicle classes are quite similar. This is somewhat unexpected, as a larger vehicle would appear to require a larger lag. This counterintuitive result is likely due to the geometric definition of lag used herein. The maximum variation in the median value is less than 15% for right turns, and less than 4% for straight-thrus.

However, recall that the lag is defined by the time at which a vehicle leaves a specified region. If acceleration rates are assumed constant, a short vehicle will vacate a region more quickly than a larger vehicle. Moreover, longer vehicles generally accelerate at a lower rate than smaller vehicles, thereby requiring even more time to vacate a region. Thus, if measured from the time a vehicle began to pull out, clearly longer/larger vehicles require lags of greater length.

The data in FIGURE 3 and TABLE 4 indicate that drivers accept similar levels of traffic exposure regardless of vehicle classification (i.e., it doesn’t appear that drivers of large vehicles will choose smaller lags because their risk of injury in a crash is less). Because the level of exposure is similar, the timing of alerts and warnings will be related to vehicle size/length. This is fortuitous in that vehicle size/length can be computed at the intersection in real-time.

**Waiting for a lag**

**Stop bars**

Prior work on the effect of the time a vehicle waits for a lag on the accepted lag time has shown a negative correlation (2), (13). To validate this result, an analysis was conducted in which lag times were correlated with time waiting to accept the lag. The analysis was conducted for both vehicles waiting at the stop bar (zone 1 and 2) and for vehicles waiting at the yield sign in the median (zone 7 and 8). Distributions of the time drivers spent in the stop sign zones (1 and 2) of CSAH 9 and in the median crossroads are shown in FIGURE 4.

FIGURE 4 and TABLE 5 show that the lag accepted either at the stop bar is slightly negatively correlated to the time spent in either location. The longer the time in the median, the shorter the median accepted lag, but the difference in median accepted lag is less than 5%. This insensitivity indicates that effective alert and warning timing will not require information regarding the time spent by the driver in either the median or the stop bar zones.
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FIGURE 3. Lognormal distributions for right turn and straight-thru accepted lags as a function of vehicle classification. Relatively small numbers of large commercial vehicles make right turns.
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### TABLE 4. Statistics for lognormal distributions of accepted lags as a function of vehicle classification.

<table>
<thead>
<tr>
<th>Right turn/ Strght thru</th>
<th>Vehicle Class</th>
<th>Total Lags</th>
<th>Mu</th>
<th>Median, e^μ - offset (s)</th>
<th>Sigma</th>
<th>Offset (s)</th>
<th>Residual</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rt. Turn</td>
<td>Small Pass.</td>
<td>793</td>
<td>2.07</td>
<td>10.20</td>
<td>1.38</td>
<td>-2.31</td>
<td>0.024</td>
</tr>
<tr>
<td>Rt. Turn</td>
<td>Large Pass.</td>
<td>2930</td>
<td>2.18</td>
<td>10.69</td>
<td>0.84</td>
<td>-1.81</td>
<td>0.009</td>
</tr>
<tr>
<td>Rt. Turn</td>
<td>Small Comm.</td>
<td>546</td>
<td>1.99</td>
<td>9.54</td>
<td>1.65</td>
<td>-2.23</td>
<td>0.035</td>
</tr>
<tr>
<td>Rt. Turn</td>
<td>Large Comm.</td>
<td>780</td>
<td>2.11</td>
<td>10.03</td>
<td>1.38</td>
<td>-1.81</td>
<td>0.020</td>
</tr>
<tr>
<td>Strght – Thru</td>
<td>Small Pass.</td>
<td>1901</td>
<td>1.89</td>
<td>8.31</td>
<td>0.99</td>
<td>-1.69</td>
<td>0.029</td>
</tr>
<tr>
<td>Strght – Thru</td>
<td>Large Pass.</td>
<td>4608</td>
<td>1.86</td>
<td>8.26</td>
<td>0.79</td>
<td>-1.82</td>
<td>0.016</td>
</tr>
<tr>
<td>Strght – Thru</td>
<td>Small Comm.</td>
<td>860</td>
<td>1.84</td>
<td>8.01</td>
<td>1.34</td>
<td>-1.68</td>
<td>0.051</td>
</tr>
<tr>
<td>Strght – Thru</td>
<td>Large Comm.</td>
<td>1407</td>
<td>1.84</td>
<td>8.33</td>
<td>1.10</td>
<td>-1.98</td>
<td>0.053</td>
</tr>
</tbody>
</table>

**Median Crossroads**

The effect of wait time on lag acceptance for vehicles in the median was analyzed using trajectory information for zones 7 & 8. One of the purposes of crossroads surveillance is to determine the distribution of drivers who use two discrete steps to either make left turns or pass through the intersection.

Distributions of accepted lags for median waiting-time bins of 0 to 3s, 3 to 5 s, 5 to 10 s, and 10 to 60 s are shown in FIGURE 4 and the corresponding statistics are shown in TABLE 5.

Unlike drivers stopped at stop bars, the mean accepted lag exhibits no correlation with the length of time spent in the median crossroads. The variation in the median of the distributions was less than 7% across the four conditions. This lack of correlation and small variation in the median bodes well for the deployment of an effective countermeasure because alert and warning timing should be minimally affected by the duration a vehicle spends at the stop bar or in the median.

**Small Accepted Lag Analysis**

FIGURE 2, FIGURE 3, and FIGURE 4 all show a significant number of accepted lags smaller than those recommended by AASHTO in TABLE 1. TABLE 6 shows the number of lags of less than four seconds accepted for each category previously analyzed, and indicates whether small lags associated with a lag category are over- or under- represented. Overall, 3.0% of measured lags were below four seconds.

For maneuver type, the straight-through maneuver was the most commonly observed maneuver (63.5%), followed by right maneuver (36.3%), and left (.4%). Of the lags of less than four seconds, the straight-through maneuver accounted for 80.5% of these, and given that it only represents 63.5% of all maneuvers, is obviously over-represented.
FIGURE 4. Time vehicles spent in stop bar and median zones before accepting a lag.
TABLE 5. Lognormal distributions describing time waiting at stop bar and median.

<table>
<thead>
<tr>
<th>Zone</th>
<th>Time Waiting for Lag (s)</th>
<th>Total Lags</th>
<th>Mu</th>
<th>Median, e^(\mu) - offset (s)</th>
<th>Sigma</th>
<th>Offset (s)</th>
<th>Residual</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stop bar</td>
<td>5 – 12</td>
<td>301</td>
<td>1.85</td>
<td>8.03</td>
<td>2.13</td>
<td>-1.68</td>
<td>0.065</td>
</tr>
<tr>
<td>Stop bar</td>
<td>12 – 17</td>
<td>566</td>
<td>1.59</td>
<td>7.93</td>
<td>1.65</td>
<td>-3.02</td>
<td>0.065</td>
</tr>
<tr>
<td>Stop bar</td>
<td>17 – 25</td>
<td>398</td>
<td>1.71</td>
<td>7.81</td>
<td>1.88</td>
<td>-2.28</td>
<td>0.055</td>
</tr>
<tr>
<td>Stop bar</td>
<td>25 – 60</td>
<td>302</td>
<td>1.75</td>
<td>7.66</td>
<td>2.12</td>
<td>-1.90</td>
<td>0.042</td>
</tr>
<tr>
<td>Median</td>
<td>0 – 3</td>
<td>295</td>
<td>1.78</td>
<td>7.60</td>
<td>2.12</td>
<td>-1.68</td>
<td>0.061</td>
</tr>
<tr>
<td>Median</td>
<td>3 – 5</td>
<td>605</td>
<td>1.60</td>
<td>7.98</td>
<td>1.64</td>
<td>-3.04</td>
<td>0.057</td>
</tr>
<tr>
<td>Median</td>
<td>5 – 10</td>
<td>375</td>
<td>1.82</td>
<td>8.10</td>
<td>1.91</td>
<td>-1.90</td>
<td>0.056</td>
</tr>
<tr>
<td>Median</td>
<td>10 - 60</td>
<td>315</td>
<td>1.70</td>
<td>7.59</td>
<td>2.10</td>
<td>-2.12</td>
<td>0.040</td>
</tr>
</tbody>
</table>

Among drivers accepting lags of less than four seconds, vehicles executing Zone 1 maneuvers are moderately over-represented among drivers selecting gaps less than 4 seconds, whereas zone 8 is significantly over-represented. Zone 2 was significantly underrepresented, and zone 7 was moderately under-represented.

Straight-through maneuvers produce the most number of small lags. Combining this fact with the zone analysis shows that straight maneuvers across the southbound lanes of US highway 52 (zones 1 and 8) had the highest number of small lags. Further analysis showed that traffic patterns had a significant effect on not only the accepted lag, but the high number (over representation) of lags less than four seconds. The stop lights in Cannon Falls (eight miles north of the intersection) cause clustering of southbound traffic. This clustering is manifest by periods of high congestion/small gaps, followed by periods of low congestion/large gaps. The periods of high congestion/small gaps present fewer opportunities for drivers to enter or cross the traffic stream, thereby causing drivers to accept smaller gaps. In this case, traffic lights cause unintended effects, the acceptance of smaller than expected (or recommended) gaps. This phenomena is more thoroughly documented in (15).

As a function of vehicle class, the percentage of vehicles accepting a lag of less than four seconds was proportional to the percentage of vehicles in that class passing through the intersection.

TABLE 6. Statistics for small lags compared with the total gap statistics, broken down by category

<table>
<thead>
<tr>
<th>Category</th>
<th>Total Gaps</th>
<th>Total Category</th>
<th>Percent of Category</th>
<th>Total Gaps &lt; 4 s</th>
<th>Total Category &lt; 4s</th>
<th>Percent &lt; 4s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Straight Maneuver</td>
<td>14017</td>
<td>8867</td>
<td>63.3</td>
<td>421</td>
<td>339</td>
<td>80.5</td>
</tr>
<tr>
<td>Right Maneuver</td>
<td>14017</td>
<td>5086</td>
<td>36.3</td>
<td>421</td>
<td>81</td>
<td>19.2</td>
</tr>
<tr>
<td>Left Maneuver</td>
<td>14017</td>
<td>64</td>
<td>0.4</td>
<td>421</td>
<td>1</td>
<td>0.2</td>
</tr>
<tr>
<td>Zone 1</td>
<td>14017</td>
<td>2442</td>
<td>17.4</td>
<td>421</td>
<td>94</td>
<td>22.3</td>
</tr>
<tr>
<td>Zone 2</td>
<td>14017</td>
<td>3888</td>
<td>27.7</td>
<td>421</td>
<td>35</td>
<td>8.3</td>
</tr>
<tr>
<td>Zone 7</td>
<td>14017</td>
<td>4157</td>
<td>29.7</td>
<td>421</td>
<td>98</td>
<td>23.3</td>
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<tr>
<td>Zone 8</td>
<td>14017</td>
<td>3104</td>
<td>22.1</td>
<td>421</td>
<td>194</td>
<td>46.1</td>
</tr>
<tr>
<td>Classification 1</td>
<td>14017</td>
<td>2712</td>
<td>19.4</td>
<td>421</td>
<td>93</td>
<td>22.1</td>
</tr>
<tr>
<td>Classification 2</td>
<td>14017</td>
<td>7565</td>
<td>54.0</td>
<td>421</td>
<td>222</td>
<td>52.7</td>
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<tr>
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<td>14017</td>
<td>1411</td>
<td>10.1</td>
<td>421</td>
<td>44</td>
<td>10.5</td>
</tr>
<tr>
<td>Classification 4</td>
<td>14017</td>
<td>2200</td>
<td>15.7</td>
<td>421</td>
<td>59</td>
<td>14</td>
</tr>
</tbody>
</table>
CONCLUSIONS AND FUTURE WORK.

The intersection surveillance has provided new insight into the (macroscopic) behavior of drivers at rural expressway intersections. A surprisingly large number of drivers are selecting lags significantly smaller than the AASHTO recommendations. At this intersection, 3.0% of drivers accepted lags are of four seconds or less.

A full instrumentation suite facilitates the macroscopic analysis of lag acceptance behavior, and provides a means to correlate this behavior with weather, time of day, road surface conditions, and a host of other parameters. The next step is to provide a more microscopic view of driver behavior. This will be accomplished by deploying a license plate reading system at the intersection. Time-stamped license plate data will be used to correlate registered driver information (i.e., age, perhaps gender) with gap acceptance trends. Although not definitive (the registered owner need not be driving), it should provide some indication on driver age and lag acceptance preferences.

It is important to note that the data collected at US 52 and CSAH 9 may not be representative of other intersections in Minnesota or in other states. Through State Pooled Fund Project TPF-5(086), a mobile intersection surveillance system was developed (16). This system will be transported to partner states, where lag acceptance behavior will be recorded at intersections with higher than expected intersection crash rates. Subsequent analyses will reveal whether quantifiable state-by-state or regional differences exist in macroscopic lag acceptance behavior. Early identification of these differences will lead to the development of a ubiquitous IDS system, deployable throughout the US.

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REFERENCES