# Analysis of Driver Behavior and Operations at Intersection Short Lanes

SAFETY RESEARCH USING SIMULATION

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# Abstract

With the ever-increasing demand to add roadway capacity in a safe and efficient manner, the application of auxiliary through lanes (ATLs) at intersections has increased in recent years. ATL intersections exist when there is an added through lane introduced upstream of a traffic signal and removed downstream of the intersection via a gradually tapered merge. In theory, these lanes increase the capacity of signalized intersections with minimal, if any, impact on safety; however, the intersection geometry presents several unique challenges for drivers. Furthermore, the benefits of increased capacity are only realized when drivers are making decisions that maximize the utilization of the introduced ATL and safety is not compromised.

The current research effort employed driving simulation, microsimulation, and field study to evaluate the operational efficiency of ATLs and driver performance elements related to their operation. The initial hypothesis evaluated the extent to which current field operations are reflective of modeled or predicted operations. This was evaluated in microsimulation and considers traditional intersection performance measures amongst others. Subsequent to that initial analysis, the remaining hypotheses evaluated are primarily related to ATL utilization. More specifically, the focus is on which factors contribute to drivers' decision making regarding use in these intersections. The driving simulation portion of this research investigates human decision making at ATL intersections. This behavioral data was evaluated against our previous findings in microsimulation and in the field. The results provide evidence to suggest optimal ATL design for maximizing driver performance and, subsequently, intersection capacity and safety.

# Introduction

## 1.1 Auxiliary Through Lane Design and Lane Utilization

An auxiliary through lane (ATL) may be added at signalized intersections with the intent to maximize the capacity of the intersection. Many studies have referenced the variety in geometric design of ATLs, such as taper lengths, both upstream and downstream of the intersection. These studies have been motivated from previous field studies that observed the utilization of continuous through lanes (CTLs) and ATLs at intersections to be unbalanced at roughly 80% and 20%, respectively [1]. This leads to the question of whether or not auxiliary lane design impacts this unbalanced utilization. Tarawneh et al. [2] suggest that there is a significant impact on intersection performance with the upstream length of the auxiliary lane, stating that longer auxiliary lanes produced a greater volume of through traffic as opposed to shorter auxiliary lanes.

Additional studies have been performed in reference to the deceleration area in an approach to a taper lane entrance. The results provide a standard distance required to allow for lane changes [3], which will be used to modify the American Association of State Highway and Transportation Officials (AASHTO) Green Book [4]. The research objective of this paper is to study the impact of the upstream taper of an ATL as it relates to the awareness of a driver approaching an ATL, which is directly correlated to the lane's utilization. There are many variables that may alter driver behavior when approaching an intersection with an ATL. These behaviors may vary depending on the surrounding area (rural, urban, etc.). According to Ring et al. [5], it is possible to determine a fluctuating value of lane utilization from multiple sites located in two different cities, which means that there may be different outcomes for different location types. As a result, the geometric design of ATLs may have a huge impact on lane utilization at intersections.

## 1.2 Microsimulation Lane Utilization

An important form of analysis in the field of transportation engineering is the use of simulation models, which are created during the design process in order to predict the performance of a particular intersection. Many of the previously described studies utilized this form of analysis when examining the efficiency of ATLs. Microsimulation models built using VISSIM showed that some of the primary reasons leading to a change in lane utilization directly correlated to travel time savings. Ring et al. [5] utilized microsimulation to evaluate the lane merge distance downstream of an intersection with an ATL. This study found that drivers would merge at approximately 100 feet downstream of the intersection exit.

Microsimulation models need to be adequately calibrated to allow for an accurate representation of reality. Parameters that need calibration include gap acceptance and car-following behavior, which are very important in determining utilization of ATLs. Recent studies have resulted in alterations of these calibration factors, leading to more accurate simulated results. By improving these calibration factors, Bugg et al. [1] have increased the validity of these microscopic models to allow for a more accurate prediction of intersection performance. The microsimulation software VISSIM uses two change algorithms when predicting lane control assignment: voluntary and mandatory [6]. Nevers et al. [7] evaluated these lane changing algorithms and found VISSIM's lane change distance factor to be the best predictor of lane utilization. This calibration factor was utilized when attempting to match the field-observed utilization that Nevers et al. experienced in the field.

### 1.3 Geometric Design of a Downstream Merge

An important aspect in the addition of ATLs at intersections is the merge that proceeds downstream of the intersection. Most intersections involve the standard flow from right to left or right-lane to left-lane merge. These standard merges may be altered by increasing or decreasing the taper length downstream of the intersection. Altering the taper length affects the driver's judgment for merging from one lane to the other. It has been found that drivers are more controlled in their ability to merge efficiently and safely when there is a greater length of taper [8]. These tapers are recommended to be longer than the standards that may be calculated using the formula provided in the Manual on Uniform Traffic Control Devices (MUTCD) [9]. The equation appears as

$$L=WS \qquad (1.1)$$

where L = length of the transition area (feet), W = width of the lane (feet), and S = speed limit posted, 85$^{th}$ percentile speed, or calculated speed (miles per hour).

Along with the geometric design of the taper downstream of the intersection, there are studies involving the design of the downstream two-lane merge system. As stated previously, the standard merge used most frequently at intersections involving an ATL is a right-lane into left-lane merge. However, the new method being introduced in recent literature is the "joint-merge" concept. By altering the design of the downstream merge, there may be an effect on the capacity of the intersection, providing a modification to lane utilization. These joint merges have been introduced in highway work zones and are applied with a dual-side taper method instead of the standard single taper [10]. Joint merges are anticipated to create an even distribution of vehicles in each approaching lane as well as to reduce the number of lane changes made when approaching a lane drop. Furthermore, this alternative merge has been tested at signalized intersections and has been proven to improve overall traffic flow and safety at downstream merges [11]. However, this joint-merge study was not performed at an intersection involving ATLs. This alternative merge downstream of the intersection will have a great effect on driver decision making upstream of the intersection, specifically when it involves an ATL. Other studies related to the lane geometry downstream of an ATL have shown a correlation between lane utilization and ATL length downstream of the intersection. There is a significant increase in auxiliary lane usage with an increase in lane length downstream of the intersection [2]. The design of the downstream taper and merge are crucial to the concept of ATLs and will have a large impact on the performance of the intersection.

### 1.4 Safety Concerns in Design Alternatives

Over six million vehicle crashes occur in the United States every year (11), which makes safety a major focus in transportation design. The implementation of ATLs must be designed to certain specifications while keeping safety as a priority. For example, the merging that results downstream of the intersection may lead to more crashes when compared against a CTL-based roadway. Many ATL intersections were studied, and it was shown that only 4.5 crashes (sideswipe and rear-end) were averaged over a given year [7]. This shows that safety is taken into account during the design of these intersections. When observing the “joint-merge” concept, Wolshon et al. [10] found that this new alternative merge system provided an increase in not only driver mobility, but driver safety as well. These new alternatives can lead to safer roadways, specifically for intersections involving ATLs. By researching safer configurations of ATL design, the number of crashes per year will surely decrease.

## 1.5 Research Motivation and Objectives

This research provides an analysis on the unbalanced lane utilization occurring at ATLs through the means of microsimulation and driving simulation. There are geometric design alternatives that lead to a variance in this unbalanced lane utilization, and these new alternatives can lead to safer roadways. By researching safer configurations of ATL design, the number of vehicle crashes per year will decrease while the efficiency of the roadways will increase.

## Methodology

To evaluate the efficacy of multiple ATL design configurations, three methodological components were employed: a field study, a microsimulation study, and a driving simulation study. The following sections provide details on each of these three studies.

### 1.6 Field Study

This field study was performed using a case study approach with an intersection located along Route 9 in Hadley, MA, which is shown in Figure 0.1. A field site visit was made in order to collect intersection volume data and to further understand the utilization of the ATLs. The data was collected during each visit using video cameras that were located on either side of the intersection. The site visit occurred during a weekday PM peak period and was collected with two hours of video data.

During this site visit, two cameras were utilized far upstream of the signal in each direction. Each camera was able to capture both queue length data and volume data for the eastbound and westbound approaches of the intersection. Note that, for each of these volume data collections, the CTL and ATLs were counted separately in order to determine lane utilization.

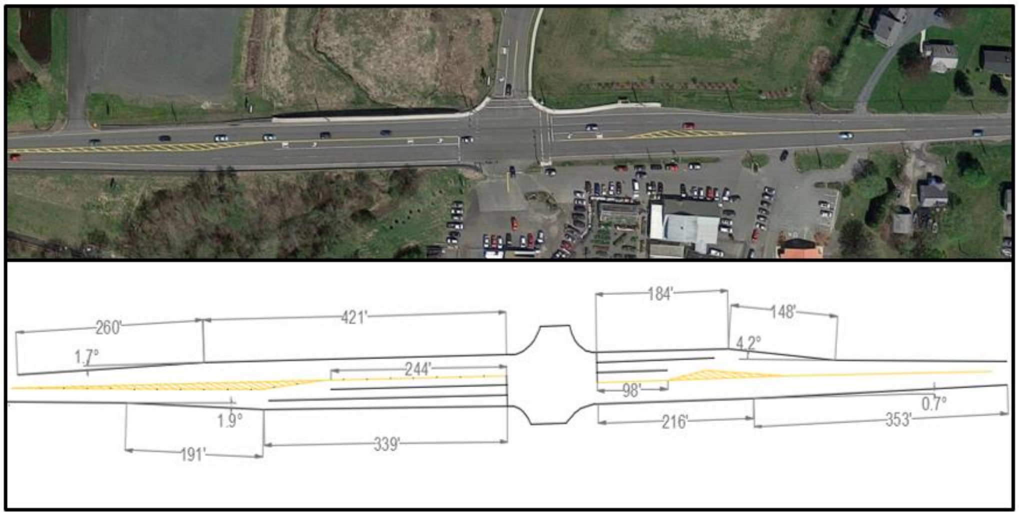


**Figure 0.1 - Study location on Route 9 in Hadley, Massachusetts**

### 1.7 Microsimulation Model – Synchro/SimTraffic

A microsimulation model was utilized in this study, using Synchro 9 [13]. This model depicted the same intersection studied in the field located in Hadley, MA. The modeled intersection involves one CTL as well as ATLs in both the eastbound and westbound approaches, shown in Figure 0.1. The intersection is located in a rural area; however, this particular location experiences a large volume during peak hours. Following the completion of model development, a calibration was required in order to analyze the overall performance of this intersection.

### *1.7.1 Model Calibration*

The volume and lane utilization data collected in the field were used to calibrate the Synchro model. In particular, the lane assignment of each vehicle when passing through the intersection was used. The volume data collected from each site visit was input as the model intersection traffic volume. Additionally, the observed values for lane utilization in the field were input to our model. This utilization adjustment allowed for the model to properly represent the chosen intersection.

Another parameter for calibration was the intersection geometry, including the ATL lengths, taper lengths, and storage lengths for the eastbound and westbound approaches. These values were obtained by aerial images via Google Earth and used to develop the microsimulation model.

### *1.7.2 Model Validation*

For the process of validating the lane utilization of this model, volumes collected with video data of both site visits were utilized. The Synchro model was run, and the results were compared with the video data, focusing on lane utilization and queue length in the eastbound and westbound approaches. As a result, the model was validated through the means of reproducing results similar to those obtained in the field study. In addition, the queue results from this model were implemented into the experimental design of the driving simulation portion of this study.

## 1.8 RTI Driving Simulation Model

The Arbella Insurance Human Performance Laboratory, located at the University of Massachusetts Amherst, was used for the driving simulation portion of this research. This full-cab driving simulator is equipped with 135 degrees of view, processed through four advanced Realtime Technologies (RTI) simulator servers. The roadway environments that the drivers traversed were constructed through AutoCAD Civil3D, the mesh modeling program Blender, and Internet Scene Assembler (ISA).

### *1.8.1 Model Creation & Internet Scene Assembler*

In order to emulate the intersection observed in the field study, an AutoCAD Civil 3D model was generated according to the geometric design specifications shown in Figure 0.1. Further, in development of this model, it was determined that the dedicated left turn lane in each direction was not applicable to this research and therefore was left out of the design. Next, the Civil 3D file was exported into the 3D modeling program, Blender. Once all of the roadway sections (i.e., pavement, sidewalk, curbing, and markings) were texturized, the files were exported into ISA, and the virtual world was constructed around the imported roadway tile, seen in Figure 0.2.

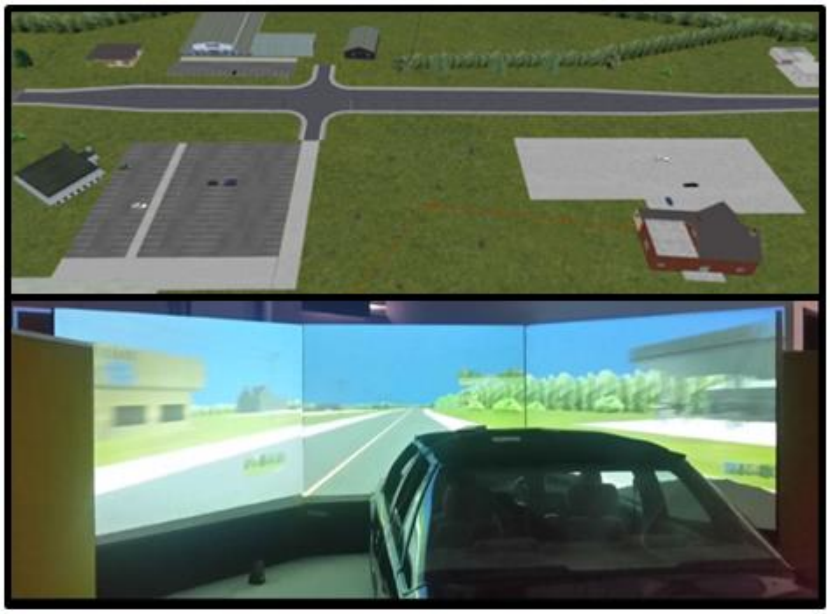

**Figure 0.2 - RTI driving simulator and ISA model at the University of Massachusetts Amherst**

### *1.8.2 Experimental Design & Post-Questionnaire*

The basis of the experimental design was derived from the preceding field study and microsimulation modeling. The three independent variables listed at the top of Table 0.1, familiarity concept, lane length design, and queue length, were proven to be reliable variables that yield strong results in the driving simulator.

From previous research completed in the field study, the impact of ATL lengths on intersection performance became apparent. The performed driving simulation study was intended to investigate the impact of long and short upstream segments in combination with long and short downstream segments on the intersection performance. In addition to this variable, the queue lengths in each approach lane were analyzed. Following the analysis completed during the microsimulation modeling portion of this research, a threshold of queue break points was developed. These break points were used to provide the drivers with alternative approach queues. Lastly, the idea of a familiarity concept was considered in the experimental design in order to further analyze the driver behavior of each participant. With this, the participants would complete four of their scenarios without a clear knowledge of ATLs. Following the fourth scenario, the researcher conducting the experiment showed the participant a picture of the intersection on Route 9 in Hadley, MA. Then the researcher briefly explained the concept of ATLs. Finally, each participant drove the final four scenarios with the general understanding of ATLs. The concept of familiarity allowed for the creation of only four different scenarios in this design.

**Table 0.1 - Experimental design of the RTI driving simulator study**

| Familiarity Concept | Lane Length Design | CTL Queue | ATL Queue | Scenario Number |
|---|---|---|---|---|
| Unfamiliar (ATL Concept Concealed) | Long Upstream Taper/ Short Downstream Taper | 5 vehicles | 0 vehicles | 1 |
| | | 5 vehicles | 2 vehicles | 2 |
| | Short Upstream Taper/ Long Downstream Taper | 5 vehicles | 0 vehicles | 3 |
| | | 5 vehicles | 2 vehicles | 4 |
| Familiar (Introduced to ATL Concept) | Long Upstream Taper/ Short Downstream Taper | 5 vehicles | 0 vehicles | 5 |
| | | 5 vehicles | 2 vehicles | 6 |
| | Short Upstream Taper/ Long Downstream Taper | 5 vehicles | 0 vehicles | 7 |
| | | 5 vehicles | 2 vehicles | 8 |

Note: CTL = continuous through lane, ATL = auxiliary through lane

Each of the virtual drives was composed of a total length of around 600 meters with the main ATL intersection tile, surrounded by a 200-meter-long filler tile on each end. These drives typically took 30-45 seconds to complete, depending on the participant, and a 45 mile per hour speed limit was set for the participant to see at the beginning of each scenario. All of these drives consisted of straight drives, limiting the participant to the single decision of changing lanes as he or she approached the intersection.

In order to eliminate any of the effects caused by the scenario order given to each participant, a Latin square was utilized to provide a balance of order. In this particular case, the Latin square was utilized for both the unfamiliar drives and the familiar drives. Thus, the order of scenarios 5-8 would reflect the same order as the first four scenarios. With a Latin square, each scenario will appear only once in every row and column.

Thirty-two drivers (16 males, 16 females) from around the University of Massachusetts Amherst area were recruited and compensated to participate in this study. The ages of participants ranged from 18 to 62 years old with an average age of 23.6 years (SD = 7.9 years). According to the pre-study questionnaire that was given to each of the participants to collect demographic information, the average driving experience was seven years. In addition, only seven of the 32 participants had previous experience in the driving simulator.

Following the eight driving scenarios that each of the 32 participants experienced, a post-study questionnaire was given to each individual. This questionnaire consisted of questions relating to ATL familiarity and opinions on geometric design, particularly the downstream merge design. The final two questions of the questionnaire informed the driver of the joint-merge concept mentioned previously. Each participant was given the opportunity to explain his or her thoughts on the existing design of ATLs compared to to the new central merging scenario.

## Results

### 1.9 Field Study vs. Microsimulation Model

The field data collection focused on lane utilization in the eastbound and westbound approaches as well as the average queue lengths that existed at each red phase. The results from this lane utilization are observed in Table 3.1. This table represents the total approach volume for each of the two main approaches. The $F_{LU\_AUX}$ factor that is utilized in this analysis is an alternative form of the standard lane utilization factor ($F_{LU}$). This analysis allows for determining specific percentages of through vehicles for each of the approach lanes. As seen in table 3.1, the eastbound approach resulted in a lane distribution of 23% and 77% for the ATL and CTL, respectively. Here, this lane distribution compares well to the predicted standards of 20% and 80% for ATLs and CTLs (2). The westbound values (10% and 90%) on the other hand, are inconsistent with these standards.

**Table 0.1 - Lane utilization data observed from field site visit**

| | Auxiliary Through Lane | Continuous Through Lane | Total Approach Volume (vph) |
|---|---|---|---|
| Eastbound Approach (vph) | 184 | 631 | 815 |
| **$F_{LU\_AUX}$** | 0.23 | 0.77 | - |
| Westbound Approach (vph) | 92 | 781 | 873 |
| **$F_{LU\_AUX}$** | 0.10 | 0.90 | - |

The main takeaway from these results is the difference between the $F_{LU\_AUX}$ factors for each approach. The results from the data collection on the westbound approach demonstrate extremely low percentages utilizing the ATL (10%). This value is much lower than the previously stated expectation (standard distribution of 20% for ATLs), and our analysis shows that there are multiple factors that correlate to this uneven distribution. The westbound ATL length is approximately half the length of the eastbound ATL, shown in Figure 0.1. Additionally, the upstream taper length in the westbound approach is shorter than the taper in the eastbound direction. These geometric variations directly correlate to the big differences in lane utilization between the two approaches shown in Table 0.1.

The results from the Synchro model focused on maximum and average queue lengths for both approaches. Table 0.2 shows the queue length values observed in the field. These values were estimated using the same vehicle length that Synchro utilizes, which is 25 feet per vehicle. The data was collected, and the resulting maximum queue lengths and average queue lengths were tabulated while being separated into CTL and ATL. The results from Synchro in Table 0.2 represent the output from the microsimulation model.

These results in Table 0.2 show similar trends in terms of comparing the two different approaches with each other. In this case, the eastbound approach CTL is similar in terms of maximum queue lengths. The reasoning behind this is directly connected to the greater lane utilization of ATLs in this direction.

**Table 0.2 - Queue data output from field site visit and Synchro model**

| **Field Site Visit Data** | | | | |
|---|---|---|---|---|
| **Movement** | Eastbound | | Westbound | |
| Directions Served | CTL | ATL | CTL | ATL |
| Maximum Queue (ft) | 200 | 150 | 275 | 50 |
| Average Queue (ft) | 140 | 32 | 113 | 15 |
| Storage Bay Distance (ft) | - | 339 | - | 184 |
| **Synchro Data** | | | | |
| **Movement** | Eastbound | | Westbound | |
| Directions Served | CTL | ATL | CTL | ATL |
| Maximum Queue (ft) | 201 | 23 | 156 | 100 |
| Average Queue (ft) | 69 | 2 | 63 | 11 |
| Storage Bay Distance (ft) | - | 339 | - | 184 |

The results in these tables are ultimately used for determining not only the queue length, but more importantly the influence the queue length will have on the driver. These average queue lengths were then applied to the experimental design of the driving simulator study.

## 1.10 Significance of Driver Performance Results

An analysis of the driving simulation study was completed once all of the 32 participants completed the eight driving scenarios. As previously mentioned, the scope of this research involved an analysis of the three key variables that were determined to have the largest impact on ATL utilization: queue length, ATL length, and familiarity with ATL intersections.

The results from each of the 32 participants are displayed in Figure 0.1. Each of the scenario results are displayed as a percentage of lane utilization, in particular with CTL and ATL. As previously stated, the experimental design allowed for repetition of four scenario models, once in the unfamiliar state and once in the familiar state. These results suggest that there is a significant lane utilization variance between being unfamiliar and familiar with the operations of ATLs.

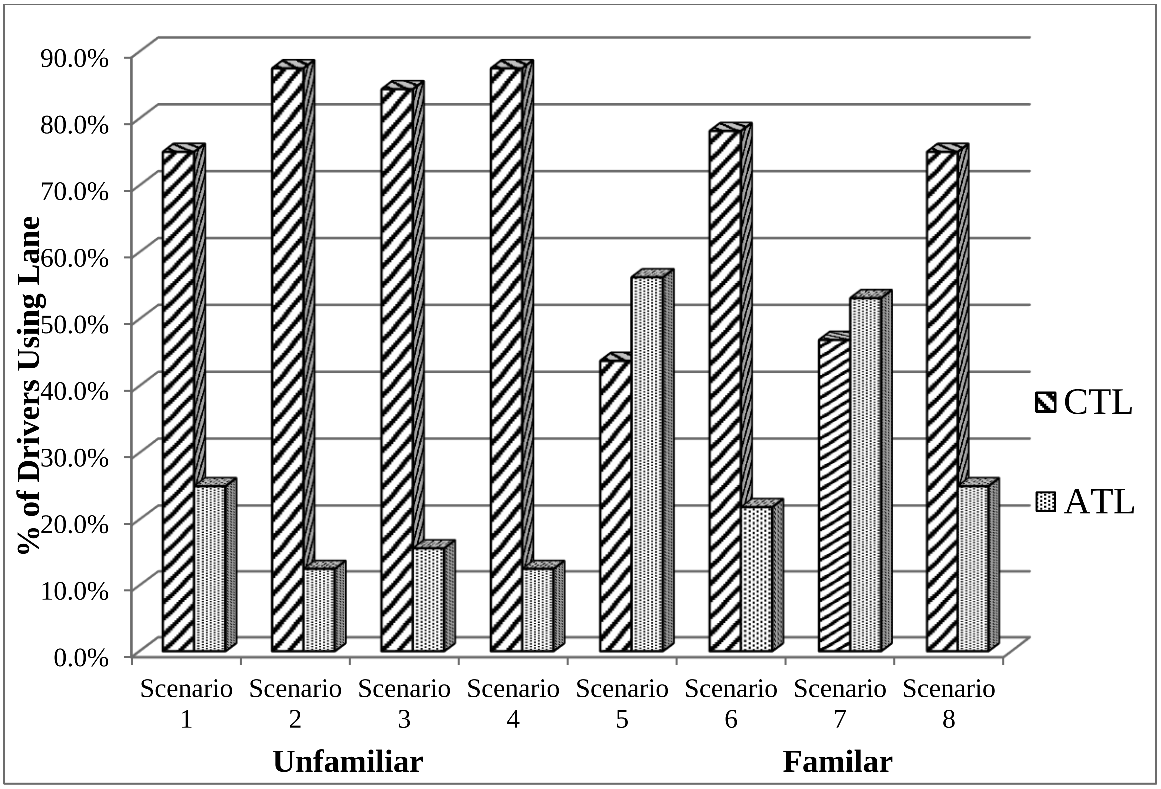


**Figure 0.1 - Driving simulation study results**

To test the statistical significance of the queue length, ATL length, and familiarity with ATL intersections, a collection of paired t-tests was performed in Microsoft Excel. All of the statistical comparisons are further explained below, and can be seen in Table 0.3.

Using the experimental design presented previously, the independent variables were analyzed against one another based on the scenario in which they appeared. For instance, the queue comparison varied by every other scenario (from scenario 1-8), as scenarios 1, 3, 5, and 7 all contained a five-vehicle queue in the CTL and no queue buildup in the ATL. The other scenarios

(2, 4, 6, and 8) contained a five-vehicle queue in the CTL as well as a two-vehicle queue in the ATL. The results from this queue length variability are provided in Table 0.3. In addition to the queue variable, this study also tested the factor of ATL length, both upstream and downstream of the intersection. Again, the results from these analyses are provided below.

Lastly, the familiarity concept was tested to determine the significance of driver familiarity with ATLs. As seen in Table 0.3, this was the only variable to yield strong statistical significance (p=0.0001). As a result, it may be concluded that when drivers become familiar with the roadway around them, they adapt and ultimately begin to alter their decision-making. In this case, the drivers were less likely to choose the ATL when they were unfamiliar with it; however, once they became aware of the application of an ATL, they were much more likely to utilize it.

**Table 0.3 - P-values from paired t-tests for statistical significance**

| P-Values from Paired t-tests | | | | | |
|---|---|---|---|---|---|
| Queue vs. No Queue | Scenario 1 & 2 | Scenario 3 & 4 | Scenario 5 & 6 | Scenario 7 & 8 | Total |
| | 0.16 | 0.71 | <0.01 | <0.01 | 0.87 |
| Familiar vs. Unfamiliar | Scenario 1 & 5 | Scenario 2 & 6 | Scenario 3 & 7 | Scenario 4 & 8 | Total |
| | <0.01 | 0.16 | <0.01 | 0.16 | <0.01 |
| Long/Short vs. Short/Long Lane Length | Scenario 1 & 3 | Scenario 2 & 4 | Scenario 5 & 7 | Scenario 6 & 8 | Total |
| | 0.18 | 1 | 0.66 | 1 | 0.44 |

* Statistical significance indicated by a P-value ≤0.05 and a shaded box

## Discussion

This research investigated the factors leading to unbalanced lane utilization of ATLs through field, microsimulation, and driving simulation studies. The factors affecting lane utilization were determined to be queue length, ATL length, and familiarity with ATL intersections.

### 1.11 Analysis of Driving Simulator Data

Drivers were presented with an assortment of eight scenarios in the driving simulator and were asked to drive each scenario as they would normally. These scenarios involved deciding whether to use an ATL or to continue straight through the intersection without changing lanes.

It is apparent that drivers are more comfortable with using the ATL if they have been exposed to its purpose as evidenced by the drastic increase in ATL utilization for nearly all of the 32 participants after becoming familiar with the concept of ATLs. On the other hand, it is apparent that the variability of queue length in each of the through lanes had no effect on driver lane choice at ATLs. However, it is important to note that the depth perception that is created from the simulator may be deceiving to the driver. The difference between a queue of five vehicles and a queue of two vehicles was not as apparent as it would be on a real roadway. The result from this queuing variable leads to the belief that an increased variance in queued vehicles may better align with the results in previous literature [1].

The geometric design of the ATLs did not yield strong significance in terms of lane utilization. Drivers were not willing to alter their lane choice based on the length of lane that was located upstream of the intersection. In some cases, drivers may be more willing to utilize the ATL based on the downstream merging length. Drivers seemed to dislike the drastic downstream merge that was required during some of the scenarios compared to other scenarios that provided ample space/time to safely merge back into the single lane. The results from this lane length variability contradict previous literature that shows a major difference in volume for ATLs with longer upstream lengths [2]. However, the results from this driving simulator study yield insignificant lane variability data, which may be a result of the small sample size. Further analyses and studies would better prove this concept of lane length variability and ATL utilization.

### 1.12 Post-Study Questionnaire Analysis

A post-study questionnaire was issued to each of the 32 participants following their completion of the eight driving simulation scenarios. The questionnaire consisted of questions relating to familiarity with ATL design. In summary, the majority of the participants were familiar with the appearance of ATLs; however, they lacked operational knowledge. Further, each of the 30 participants who were familiar with ATLs were also familiar with the study intersection located on Route 9 in Hadley, MA.

The first two short-answer questions that appeared on the questionnaire pertained to the opinion of the ATL design. Specifically, these questions addressed the participant's general opinion of ATLs and their supposed effectiveness. Many of the participants were accepting of the current design of ATLs; however, many of them argued against the downstream merging scenarios. Though they believed it to be an efficient solution, many drivers were irritated by the abruptness of the downstream merge and would have liked to have more time to merge from the right lane to the left lane. Overall, the results from these questions provided a summary of the driver beliefs on current ATL design.

The final two questions pertained to the participant's opinion of the joint-merge or central-merge concept. This concept is an alternative design to the downstream merge of the ATL into the single CTL. Each participant was asked to give his or her opinion of the central merge idea as an alternative to the existing conditions. Many participants were hesitant to give the new concept credit, as they believed it to be a confusing design. Clearly, this alternative design would necessitate training at the young driver level. Many participants believed it to create a greater concern for safety in terms of vehicle merging collisions. The questionnaire also presented the picture shown in Figure 0.1 , and participants were asked to select the sign that they believed to be the most impactful. The two left-most sign displays were chosen as the favorites in this case. Specifically, a greater number of participants seemed to be attracted to the idea of a text-based sign display, as opposed to one with only an image of the standard merge design. This conclusion confirms that this group of participants, though a small sample size, would find a central merging sign with text more appealing than a simple image. These results should inform the future research of central merge design.

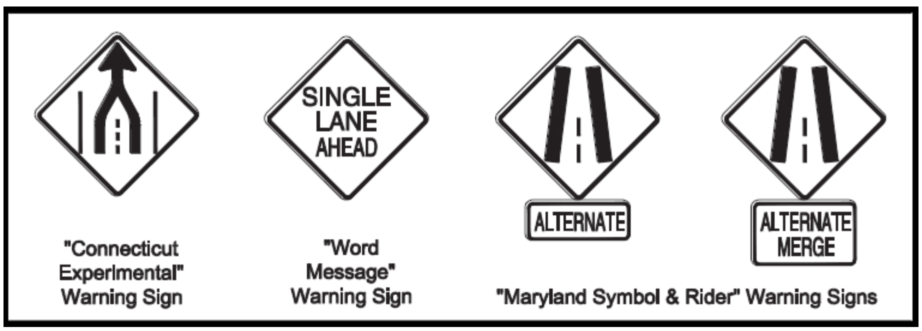


**Figure 0.1 - Example of alternative merge signs (8)**

## Conclusion

Auxiliary through lanes were observed via a field study, a microsimulation model, and a driving simulation that emulating a rural signalized intersection. The field study verified the concern of underutilization of ATLs and analyzed the geometric design variance in causing this concern. A microsimulation model was utilized to further develop evidence for underutilized ATLs as well as to provide evidence about typical average queue lengths at ATL intersections. The driving simulation study developed a human behavioral perspective in understanding the reason behind this problem. The design of this study focused on combining the geometric design alternatives and the queue variance to determine whether they had a significant impact on the driver. While the strongest statistical significance lay with the basis of familiarity versus unfamiliarity of ATLs, the downstream merging design proved to affect the drivers significantly. Future research should target this downstream merge geometry to determine whether a joint-merge design would lead to better intersection performance. A modification in the downstream design of these intersections could lead to a more balanced utilization of ATLs and CTLs in the upstream and, therefore, result in higher performance of the intersection.

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