Using Population Models to Validate Platzer’s Methodology for Overcoming Vehicle Side Mirror Blind Spots

Brendan McNelly\textsuperscript{a}, Chris Monaco\textsuperscript{b}, Dr. Matthew Parkinson\textsuperscript{c}

\textsuperscript{a,b,c} Mechanical Engineering, Pennsylvania State University, University Park, PA, USA;

Abstract: One recommended practice for remediating field-of-view issues (“blind spots”) in automobiles (Platzer, 1995) claims to completely eliminate blind spots for the driver population if a driver adopts a specific posture during the driver-side mirror adjustment phase. Variability in posture and body size and shape were included due to effects on seated eye location. Using data from literature, along with published vehicle dimensions and anthropometric data of the United States population (ANSUR and NHANES) regression models with residual variance were built. These models allowed virtual fitting trials of the populace in different vehicles to occur. Using vector analysis and eye location, the percentage of the blind-spot area that is covered by side-mirror visibility was determined when virtual trials occurred. An analysis of a wide range of vehicles shows that Platzer’s method is validated to eliminate side mirror blind spots for a minimum vehicle length of 13 feet for 90\% of the population.

Practitioner Summary: Drivers of automobiles use a system of mirrors to provide visual feedback of the environment immediately around the vehicle. Common practice has been shown to reduce—but not eliminate—regions that are not visible to the driver. The method outlined in this paper is shown to be effective for approximately 90\% of the population. Drivers should consider modifying their strategy to the one proposed by Platzer in 1995.

Keywords: Blind spots, Platzer, vector analysis, mirrors, automobiles

1. Introduction

An automotive blind spot is “an area around a car, truck, etc., that the driver cannot see” (Blind Spot, n.d.). The use of the mirror is an attempt to improve safety by minimizing these regions and the amount of head movement required by a driver trying to assess them.

There are two main types of automotive blind spots: mirror blind spots and structural blind spots. Mirror blind spots describe the blind spots that exist despite a mirror’s use to extend visibility to that region. Structural blind spots describe the blind spots that exist because the vehicle’s structure itself obstructs the driver’s line of sight from the regions surrounding the vehicle. While both types of blind spots are critical to automotive safety, only mirror blind spots are considered in this paper.

The most common mirror blind spot, the side mirror blind spot, occurs near the rear corners of the vehicle. In order to see other areas while still looking ahead and staying at the controls, the driver depends on their mirrors. For instance, the driver looks at their left side mirror to look at the next lane behind the vehicle. Unfortunately, the additional field of view offered by the mirrors are limited by their size, and therefore, not every area around the vehicle can be immediately observed. There is an area near the rear left-side of the vehicle that is not captured from either the driver’s or mirror’s field of view. This unobservable area is called the blind spot, specifically, a mirror blind spot. As seen in Figure 1, one may note that this blind spot is large enough to hide the red car from the blue car driver’s vision almost entirely.

Side mirror blind spots pose a safety risk. The existence of a side mirror blind spot is particularly dangerous during lane-change maneuvers. In fact, NHTSA, the National Highway Traffic and Safety Administration, claimed that in 2011, 9\% of all injury crashes involved lane-change maneuvers (Szigethy, n.d.). The existence of mirror blind spots and drivers’ dependency on mirrors when performing lane-change maneuvers is likely an important contributor.
1.1 Influence of Human Variability on Design

Blind spots are not just a factor of the vehicle’s design, but a factor of the driver’s interaction with the design. For side mirror blind spots, the driver’s sitting distance from the steering wheel plays a large factor into determining the size of their mirror blind spots. Dependent on leg length, for a standardized seat height and driver seat design, drivers typically adjust their seats so they are at a distance in which the ball of their foot is near the bottom of the accelerator pedal and their knees and hips are at comfortable angles. Drivers with shorter legs tend to sit closer to the steering wheel than those with longer legs. Since leg length is correlated with stature and other measures of length, those with shorter legs also tend to sit more upright.

The driver’s seat position changes the side mirror blind spot in two ways. First, the driver’s peripheral vision allows for visibility at a slight angle behind the driver. Therefore, if a driver moves closer to the steering wheel, the peripheral field of view starts closer to the front of the vehicle, increasing the relative size of the blind spot behind the driver.

Modern side mirrors are highly adjustable, sometimes offering precise electronic control of the mirror’s angle to accommodate for body size and preferred driving posture. A common side mirror adjustment technique involves adjusting the mirrors in which the car’s exterior is just visible by the driver. However, as seen in Figure 2, despite the large degree of adjustability, seat position still greatly affects the size of the mirror’s field of view. Drivers of all sizes typically follow a similar strategy of adjusting their mirrors to just barely show their car’s exterior side edge. With this common start of their field of view, the size of the side mirror determines where the field of view ends. A shorter driver’s greater viewing angle, relative to the normal of the mirror, allows for the sightline to capture a greater field of view, reducing the side mirror blind spot.

Side mirrors, in practice, rotate about the center axis of the mirror rather than the inner edge (shown in Figure 2). In addition, the optical angles presented here are greatly exaggerated to aid visual recognition. However, most importantly, the mirrors in this approximation are flat mirrors or planar. The passenger side
view mirrors of automobiles sold in the United States are convex, magnifying images. However, this paper will be focused on the study of driver side mirror blind spots and convexity is not a factor. In addition, the above approximation only considers the horizontal field of view. The vertical field of view is determined by the driver’s sitting height and the mirrors respective adjustability. However, typical side mirror design allow for a vertical field of view that is much greater than necessary to observe vehicles on a level road. Therefore, it is much less of a concern and not a focus of this paper.

1.2 Elimination of Side Mirror Blind Sports with George Platzer’s Methodology

In 1995, George Platzer published a Society of Automotive Engineers paper that claimed that a particular side view mirror adjustment can eliminate any blind spot that can hide an automobile (Platzer, 1995). He claimed that the primary reason side mirror blind spots exist is because most drivers adjust them so that the fields of vision offered by the left, rear, and right mirrors overlap. He noted that many drivers insist on being able to see the side of their car’s exterior with the side view mirrors. Platzer claimed that this did not make the best use of the mirror’s potential and created blind spots. However, using optical physics equations to validate his logic, Platzer concluded that a simple unconventional side view mirror adjustment can eliminate automotive blind spots altogether, for all drivers (Platzer, 1995).

For calibration, Platzer claimed that a driver needed to place their head adjacent to the driver’s side window and adjust the driver’s side view mirror to just barely capture the car’s edge. In addition, the driver would need to lean over so their head is perfectly in the car’s center and adjust the passenger side view mirror to barely capture the right side’s exterior. With this unconventional adjustment, mirror overlap has been eliminated, and therefore, so have the mirror blind spots (Quiroga, 2010; Jensen, 2009). Since the publishing on his paper, many professional automotive societies have accepted his findings, yet validation of his blind spot elimination claim has not been confirmed through anthropometric analyses of large driving populations.

The analyses outlined in this paper focus on validating the effectiveness of George Platzer’s blind-spot elimination method for the general U.S. driving population.

1.3 Defining a Target Population

The target user population for this study was the population of U.S. citizens aged 16 years or older. This population was selected to emulate the general driving population of U.S. citizens. The population (and its associated anthropometric data) were generated from recent National Health and Nutrition Examination Survey (NHANES) results (CDC/National Center for Health Statistics, 2014). NHANES was used to capture US citizen anthropometric stature data and the Anthropometric Survey (ANSUR) of United States military personnel was used to represent the population’s facial feature dimensions (Gordon, 1989).

2. Literature Analysis

2.1 Modeling Vehicle Occupant Head and Head Restraint Positions

Reed et. al. (2001) looks at how a vehicle occupant’s head position can be modelled based on anthropometry and vehicle dimensions. It introduces equations that model an occupant’s eye location to cover 95% of the population. The x location of an occupant’s eyes refers to the horizontal distance (parallel to the axis of the car) behind the hip point. The z location refers to the vertical distance above the hip point.

A driver’s vertical eye location as a function of stature, with respect to driver hip location, is determined through linear regression. This, with head location, allows possible analysis to solve for EyeX. The reference point for eye location in both the x and z direction is the occupant’s hip location (Reed, 2001).

\[
E\text{yeZ} = 135 + 0.2914 \times \text{Stature} + N(0.212) \quad [\text{mm}] \quad \{\text{eq 1}\}
\]

\[
E\text{yeX} = 639 \times \sin(0.719 \times \text{SBA} - 9.6) \quad [\text{mm}] \quad \{\text{eq 2}\}
\]

2.2 ATD Driver Positioning Based on Driver Posture and Position
Using a study of forty-four vehicles, Manary et al. (1998) introduces a relationship between driver hip location and vehicle parameters to analyze the effect that seat track position, seat track travel range, and design seatback angle have on a driver’s seating location. Using SAE standards, Manary builds a model to predict a distribution of driver-selected seat positions for a population in any passenger vehicle. Results show that driver stature, rather than seat track and seatback angle, more effectively predicts driver sitting location.

The equation for seating preference calculate predicted mean seat position (forward of the steering wheel) as a function of seat height (h), accelerator heel position (AHP) to steering wheel center distance (w) and seat cushion angle (p). Equation 3 is for medium stature individuals, 4 is for small individuals and 5 is for large individuals. The new model developed results in “ATDs being places in positions that are representative of the driving position of the size of people that the ATDs represent” (Manary, 1998).

\[
\begin{align*}
\mu_{mm} & = 776 - 0.24h - 0.59w - 2.19p - 119.77 \cos(78.96 - 0.015h - 0.0017h^2) \quad \text{(eq 3)} \\
\mu_{sf} & = 671 - 0.24h - 0.59w - 2.19p - 119.77 \cos(78.96 - 0.015h - 0.0017h^2) \quad \text{(eq 4)} \\
\mu_{sm} & = 827 - 0.24h - 0.59w - 2.19p - 119.77 \cos(78.96 - 0.015h - 0.0017h^2) \quad \text{(eq 5)}
\end{align*}
\]

3. Virtual Fitting Trials

3.1 Building a Virtual Population Model

In order to test Platzer’s model, a large sample size that was representative of the target population was necessary. Theoretical (‘virtual fitting’) models were generated from previously constructed databases. The virtual fitting models were designed from two databases (NHANES and ANSUR) and literature (Reed, 2001; Manary, 1998). The target population is adult United States drivers with sufficient driving experience (assumed to be age 16+).

The NHANES database is a program of studies designed to determine the health and nutritional condition of adults and children in the United States (CDC/National Center for Health Statistics, 2014). Anthropometric data of this weighted population is rather sparse, however this database comes from continuously sampled populations so the values are up to date and representative of the United State population. The ANSUR database is a 1988 anthropometric study of military personnel (Gordon, 1989) used because of the large number of measures, including head measurements, and the meticulous methodology employed.

Reed (2001) uses stature for vertical and horizontal measurements of eye location. Manary (1998) also uses stature as its only anthropometric variable. However, Platzer (1995) uses a number of facial measurements. Platzer’s method requires eye location when an individual’s face is against the window. To combine the results of these three papers, four measurements are necessary: (1) stature, (2) left pupil location relative to side of the head, (3) left pupil location relative to hip center, (4) right pupil location relative to hip center.

Many of the necessary head width measurements are not part of the NHANES database so only stature was used from NHANES. A subset of NHANES that included only individuals of age 16+ was unweighted using individuals’ four year (2007-2010) weights. Weighting determined the probability of selection when a representative sample was created. Two thousand individuals were selected at random from the unweighted population to build the final sample of 2000 United States adults.

For the head-related measurements, models were taken from the ANSUR data for head breadth (HB) (“the maximum horizontal breadth of the head above the attachment of the ears”) and interpupillary distance (IPD) (“the distance between the two pupils”). Individual head dimensions were synthesized through linear regression with residual variance using models of ANSUR data (Gameau, 2007). Mean and standard deviation were calculated for each variable and regression with residual variance was applied. Final values were calculated based on the individual residual variance of each measurement; thus building a more realistic and varied final population. The calculations for the above measurements were as follows:

1) Stature = Stature [NHANES]
2) Left pupil to side of head = (HB – IPD)/2 [ANSUR]
3) Left pupil from hip = (IPD)/2 [ANSUR]
4) Right pupil from hip = -(IPD)/2 [ANSUR]
3.2 Building a Virtual Vehicle Model

A virtual test vehicle was built; having dimensions similar to those of the Toyota Camry. Eight vehicle measurements were used in the analysis: three used with Manary (1998), one with Reed (2001), and the other four for the virtual analysis to validate Plattzer’s model. For the initial analysis, each of these variables only had one defined value, as shown below:

<table>
<thead>
<tr>
<th>Variable</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seatback angle</td>
<td>25 degrees</td>
</tr>
<tr>
<td>Seat cushion angle</td>
<td>13 degrees</td>
</tr>
<tr>
<td>Seat height</td>
<td>240 mm</td>
</tr>
<tr>
<td>Wheel to BOF</td>
<td>567 mm</td>
</tr>
<tr>
<td>AHP to wheel</td>
<td>539 mm</td>
</tr>
<tr>
<td>Seat to window</td>
<td>302 mm</td>
</tr>
<tr>
<td>Seat to mirror</td>
<td>454 mm</td>
</tr>
<tr>
<td>Mirror size</td>
<td>200 mm</td>
</tr>
</tbody>
</table>

The model assumes that the window is vertical with minimal thickness and the outside of the car is at the same lateral distance as the lateral interior.

3.3 Validating Literature

The virtual population was placed in the designed vehicle to validate the literature results before continuing forward with our analysis. To validate the population eye location from Reed (2001) we verified the 90% eyeZ value accommodation, 551 to 713 mm above the sitting location. Our model showed that 91% of the sample was within the 5th to 95th percentile.

Manary (1998) was also validated by determining driver hip location. The Manary equation offset values (y-intercept) for small, medium and large individuals were 671, 776 and 827 mm. Each of these offset values was a function of stature (stature/2.26) and merged to create equation 6. Using this equation with the sample population, the resultant population (with h, w, and p previously defined) had a 90% accommodation between the 5th and 95th percentile hip locations outlined in (Miriam A. Manary, 1998).

\[ \mu = \frac{\text{stature}}{2.26} - 0.24h - 0.59w - 2.19p - 119.77 \cos(78.96 - 0.015h - 0.0017h^2) \]  \hspace{1cm} \text{eq 6}

3.4 Placing the Population in One Vehicle

For the virtual fitting trials, each individual from the population was placed in the vehicle. The driver’s hip location was found by using equation 6 based on stature, seat height, seat cushion angle and wheel to BOF distance. The driver’s eyeZ and eyeX location (relative to hip location) was found using the eyellipse equations 1 and 2. All other calculations were calculated relative to the driver hip location and defined vehicle characteristics.

Once the driver's sitting location was determined, initial calculations were done to determine where the driver’s eyes would be during specific steps of Plattzer’s methodology. During the process, a driver will either be seated in a comfortable position, or will have their window against the glass when aligning the mirror. Eye location during the driver’s seated position has the same eyeZ and eyeX value as calculated in the Reed (2001). However the driver’s left and right eyes will be offset from the hip center-line by half of the inner pupillary distance. ANSUR data were used with linear regression models to determine the individual's IPD. With the window at a specified distance from hip center-line the distance between the widow and the left pupil can be found as a function of both head breadth and IPD.

\[
\begin{align*}
\text{Wheel to hip distance (axial)} & = (\text{stature}/2) - 0.24^*h - 0.59^*w - 2.19^*p - 119.77 \cos(78.9600.015^*h - 0.0017^*h^2) \\
\text{eyeZ (vertical)} & = 135 + 0.2914^*\text{stature} \\
\text{eyeX (axial)} & = \text{eyeZ}^*\tan(0.719^*\text{SBA}-9.6) \\
\text{eye to mirror (axial)} & = (\text{AHP to wheel}) + (\text{wheel to hip}) + (\text{eyeX}) - (\text{pedal to mirror}) \\
\text{left eye on window (lateral)} & = (\text{hip center to window}) - [(\text{HB}) - (\text{IPD})]/2 \\
\text{left eye when sitting (lateral)} & = (\text{hip center to mirror}) - \text{IPD}/2
\end{align*}
\]
right eye when sitting (lateral) = (hip center to mirror) + IPD/2

3.5 Optical Sightline Vector Analysis

An optical ray analysis was performed for each driver to determine blind spot accommodation. For this analysis, the following measures were required: the longitudinal distance from the eyes to the driver’s side mirror base, the lateral distance from the left eye to driver’s side window when leaning against the window, the lateral distance from the driver’s window to the left eye when sitting normally, and the lateral distance from the driver’s window to the right when sitting normally. Vertical optical ray analyses are not critical or a factor to this study and therefore, have been ignored. Note that these values are dependent on the vehicle and assume that the driver’s head is not rotating.

The fundamental governing optics law for planar mirrors state that the angle of incidence (angle between the ray striking a surface and the normal vector of the surface) is exactly equal to the angle of reflection (angle between the reflected ray and surface’s normal vector).

The virtual subjects follow the same procedure as their physical counterparts. To calibrate mirror position, the virtual driver sits comfortably in their seat. Then, the driver leans over to position their head against the driver’s side window. As the mirror needs to be positioned to barely project the vehicle’s exterior edge while the driver is in this position, an optical ray analysis can determine this angle. This ‘calibrated’ mirror position angle is set and will then be used for subsequent calculations.

The driver then returns to their comfortable seated position. Using optics laws, the ray angle is determined from the driver’s right eye towards the outer edge of the driver’s side mirror. In combination with the “calibration” mirror angle, the outward ray angle can be calculated to serve as the blind spot boundary. The longitudinal distance behind the driver’s eyes in which a vehicle’s far corner becomes visible in the driver’s side view mirror can then be calculated. This “blind spot distance” is based on a few assumptions: lane width is the U.S. highway minimum of 12 feet, vehicles are centered lane, neighboring vehicles share the lateral dimensions of the target vehicle, and vehicles must be captured by mirrors or peripheral vision to exit a blind spot.

4. Results and Analysis

This paper defines “blind spot distance” as the longitudinal distance behind the driver’s eyes in which a vehicle’s far corner becomes visible. Platzer’s methodology suggests that all blind spots will be eliminated; thus no vehicle will be completely obstructed from the driver’s viewpoint. Therefore a driver’s blind spot is effectively eliminated if the smallest car (benchmarked to be a subcompact 13 feet in length) can be seen in the side mirror or by the driver’s peripheral vision. If a driver has a blind spot distance of less than 13 feet they will see some of the vehicle and eliminate the blind spot. For this reason, a blind spot distance of less than 13 feet denotes accommodation by Platzer’s method, and a value above 13 feet denotes dis-accommodation.

Accommodation levels were initially calculated for the 2000 individual population when placed in the Camry vehicle. The plot below shows the distribution of blind spot distance based on stature. A red line has been added to the plot to show the separating line between accommodation and dis-accommodation; all individuals below the line are accommodated.
The distribution above has an accommodation level of 99.1%. The mean blind spot distance is 11.41 feet with a standard deviation of 0.69 feet. These results show that 99 percent of individuals who sit in the test model and adjust the mirror according to Platzer’s methodology will eliminate blind spots.

In order to further assess Platzer’s methodology, the study was run on a number of vehicles. A parametric study was run with varied seat height, one seat cushion angle, and one wheel to BOF distance. Using the values listed in Manary (1998) for vehicle dimensions (h, p, and w) mean and standard deviation values were found. The 5th and 95th percentile values were then calculated, in order to test 90% of all possibilities.

<table>
<thead>
<tr>
<th>Table 1: Vehicle Spec Percentiles</th>
</tr>
</thead>
<tbody>
<tr>
<td>height</td>
</tr>
<tr>
<td>cushion angle</td>
</tr>
<tr>
<td>wheel to BOF</td>
</tr>
</tbody>
</table>

The methodology and process of obtaining results match those of the single vehicle analysis. The 27 trials were composed of combinations of 5th, 50th, and 95th percentiles of the three variables (h, p, and w). All 2000 individuals in the sample were virtual fit to the car to calculate mean and standard deviation blind spot values for each trial. The results and accommodation levels are shown in Appendix A. Twenty-five of the 27 trials accommodated 90% of the population. Only 23 of the trials passed 95% accommodation, and 14 passed at 99% accommodation. Most vehicles have values closer to the median and heat height seems to be inversely related to wheel to BOF distance rather than normally distributed. In the 90th and 95th percentile accommodation levels, all trials that did not fit accommodation levels were using vehicles with unrepresentative manufactured dimensions (low seat height and low wheel to BOF distance).

Ignoring any relationship between variables, analysis shows most vehicles will have high accommodation levels (25/27 trials have 90%+ accommodation). Additional plots of the blind spot results are in the Appendix. Plots of the 95th and 99th percentile blind spot values vs h, w or p are shown. A red line has been added at the 13 foot mark to show that all results below are accommodated and above are dis-accommodated.
5. Conclusion

In conclusion, George Platzer’s methodology is validated to eliminate side mirror blind spots for a minimum vehicle length of 13 feet for 90% of the population for a wide range of vehicles. George Platzer’s method was tested experimentally (with a 15-person sample) and virtually (with a representative population of 2000). With a fully adjustable seat, the driver’s stature has no correlation to the size of the blind spot because sitting distance from the steering wheel becomes heavily preference-based. However, when the seat is fixed at a set vertical position, using anthropometric studies, anthropometric databases, and optical ray vector analyses, the blind spot distance can be easily calculated from drive stature for a wide range of vehicles. Twenty-five of the 27 configurations considered had accommodation levels of above 90%. The two that did not fit this accommodation level are very unrealistic configurations when compared to manufactured vehicles. This analysis suggests that Platzer’s method eliminates blind spots for the target population (US drivers) for a wide range of vehicles.

George Platzer’s method works for two main reasons. Most importantly, using his method, each driver calibrates the mirror position to their specific anthropometry, ensuring a high accommodation level. Secondly, Platzer’s method fights the driver’s natural instinct to have significant visual overlap between the side and rear mirrors. Platzer’s unconventional adjustment ensures that the mirrors’ field of view barely captures the exterior of the car. By forcing calibration with the driver’s head against the window, it ensures that the mirrors are adjusted more outward, reducing the blind spot. However, despite the proven logic supporting this method, the unfamiliarity may make drivers uncomfortable creating the need for active blind spot detection and driver assistance technologies.

References


