# Frontage Camera System for Passenger Car

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***Abstract***

Today the automotive industry is highly competitive, providing immense pressure for the automakers to introduce high-performance, safe, function-rich, and fuel efficient vehicles. However, when accounting safety and function, more emphasis on the driver's vision forward, i.e. the direction of vehicle movement, should be put. This is due to the fact that it is always assumed that the driver can vision everything in front. Yet, there exists a 'frontage blind spot' located forward along the next farthest lane from the driver (the next left lane for a right-hand-drive vehicle), which makes overtaking or traffic maneuvering unsafe and inconvenient. This problem becomes the motivation for the project; to produce a prototype system that will eliminate the driver's left frontage blind spot. After the conditions involved with the blind spot problem have been studied, a model described by the main variables is set up. Then, the location of attaching the system and the camera orientation with respect to the vehicle are researched. The prototype, which is a system of a camera and a monitor, is mounted on a mid-size sedan applicable for real road conditions both during the day and night. After that it is put into test in a simulated real road condition environment, which as a result discloses its true performance and capability – measured against the driver's and passenger's visions. The frontage blind spot is mostly eliminated with the help of the prototype.

***Keywords****:* frontage camera, blind spot

## 1. Introduction

Currently, the automotive industry emphasizes more on side and rear than the front vision of the vehicle because the driver's observation is already directed along the vehicle's movement, i.e. the forward direction. Some of these emphases are the blind-spot-assist attached on the side mirrors and parking sensors, or as well-known as the 'Parktronic'. However, there exists a blind spot area on the front passenger side, which is referred to in this article as the 'frontage blind spot'. This frontage blind sport makes overtaking on the left-hand side (for a right-hand-drive car) in emergency situations very difficult and dangerous. Another situation which involves the frontage blind spot is during traffic jam situation. During traffic jam conditions, the driver may have to maneuver through the traffic. Yet again, the driver will have a complete vision around the vehicle except that of the left lane ahead due to the frontage blind spot. This makes maneuvering through the traffic via the left hand overtaking route quite difficult. At the moment, there is no system or device which directly solves the problem of revealing the frontage blind spot. Nevertheless, some car manufacturers and electronic device manufacturers have introduced systems/devices into the market to solve problem similar to revealing the frontage blind spot. For example, these systems include 'Volvo Birds-Eye-View Camera' [1], which gives drivers a view of the vehicle and its surroundings from above. The system combines four fisheye cameras (fisheye lens is a lens that gives almost 180° view), mounted on each side of the vehicle, to produce an overhead view of the truck and its surroundings. Additionally, BMW Series 7's 'Rabbit Eyes' [2] help enhance safety at junctions where the driver's vision of left and right side of the road is limited, BMW have installed "Rabbit Eyes' in their Series 7 saloon to extend the driver's vision. The Rabbit Eyes are two camera housed near the front end of the vehicle, on each side. In addition, the Isuzu D-Max's 'front view camera', which has a camera attached to the front of vehicle, gives the 190-degree view from the front left to the front right directions and helps reveal some objects in the low-height blind spots like a flower pot and do the parking [3].

## 2. Design of Frontage Camera System

Initially, the frontage camera system has to be design to meet the requirements: the system must be able to envision the frontal blind spot of the driver on the passenger's side of the vehicle as much as possible. It should have a better front vision than that from the passenger. The design will start off with the problem modeling by definition of blind spot on the passenger side. The camera and the monitor are selected based on the performance, budget, and availability. Then the camera attachment position and its offset are determined for a best possible view of the vehicle in the blind spot. The necessity of the rotation of camera is accessed. With the good selection of the camera, the monitor, and the bracket, the prototype of the system is finally created and tested for its capabilities and performance. The test set-up and the results are explained in Section 3.

### 2.1 Problem Modeling

Modeling the problem of the frontage blind spot is the first to focus; the schematic diagram of the blind spot problem in the right-hand-drive vehicle (Fig. 1) is identified with all the governing variables: '*adj*', the distance between Vehicle 1 (the driver's vehicle) and Vehicle 3 (the secondary obstructing vehicle in the blind spot), '*n*', gap distance, the distance between Vehicle 1 and Vehicle 2 (the primary obstructing vehicle) and '*m*', the lateral offset between Vehicles 1 and 2. The suitable values of these variables for many driving situations are determined both from calculations and the real situation in Bangkok traffic.

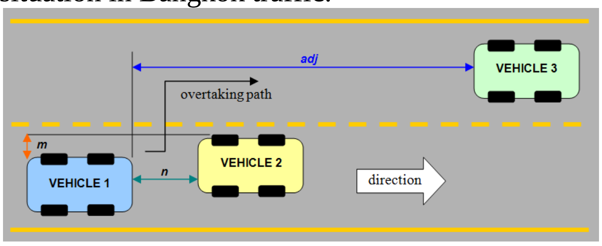



Fig. 1 Problem schematic diagram with the three governing variables

#### 2.1.1 The variable *'adj'*

The first governing variable '*adj*' is a pre-determined distance between Vehicles 1 and 3 to avoid collision. This variable is obtained from the stopping distance so that is guaranteed that Vehicle 1 will not hit Vehicle 3 as it is assumed the worst case scenario where Vehicle 3 is not moving at all. The stopping distance consists of two elements, the 'thinking distance' and the 'braking distance'. The average stopping distance for a mid-size sedan [4] is shown in Fig. 2.

#### 2.1.2 The variable *'n'*

The 'n' value, the distance between Vehicles 1 and 2, has to be calculated from the real-life situations and is dependent from the vehicles' speeds. The collection of related data was carried out on the day and at night in the Bangna Trad,

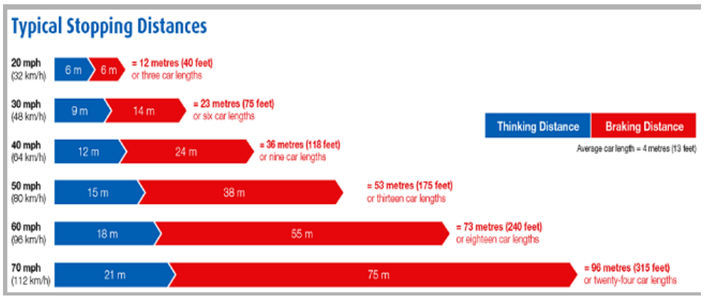



Fig. 2 Average stopping distance for a mid-size car [4]

Taeparak, and Viphawadee-Rangsit areas where two points were carefully marked and measured for the distance. The videos were taken at the locations in various traffic conditions: heavy (0-10 km/h), medium (10-50 km/h), and light (50-100 km/h). The snapshots were extracted from the videos. The distance data were then calculated and averaged out resulting in 1 to 2.4 m, 3.6 to 8.2 m, and 9.2 to 20.9 m, for the heavy, medium, and light traffic, respectively. It seems like 20.9 m for the upper limit of 'n' value is too high for further usage of the value as the driver will have clear vision of the left lane long before. Thus, this upper limit has to be set by a real-situation experiment: Vehicles 1 and 2 are in line to each other and Vehicle 3 is placed 80 m away from Vehicle 1, i.e. *adj* = 80 m, the stopping distance for a 100-km/h car). The *n* keeps changing from 5 to 20 m as shown in Fig. 3. The preliminary test indicates that approximately above $n$ = 17 m, the driver can see Vehicle 3, hence, $n$ = 17 m is the upper limit value of *n*. The lower limit of *n* is determined from the minimum front clearance of the vehicles for Vehicle 1 to overtake Vehicle 2 on the left. From the test, it is found to be approximately 1.6 m. For the safety reason, the lower limit of *n* is chosen as 2 m. Finally, the ranges of n are adjusted according to its limits and their continuity: 2 to 2.4 m, 2.4 to 8.2 m, and 8.2 to 17 m, for the heavy, medium, and light traffic, respectively.

#### 2.1.3 The variable *'m'*

Though it is assumed that both Vehicles 1 and 2 are in the same lane, it is possible that they are not exactly aligned, hence, the lateral offset *'m'*. With the track width of a mid-size car of 1.54 m and the standard width of the Bangkok traffic lane of 3 m, the possible values of *m* is between -1.46 and 1.46 m, where the negative value occurs when Vehicle 1 is on the left of Vehicle 2 and $m$ = 0 when both vehicles are in line.

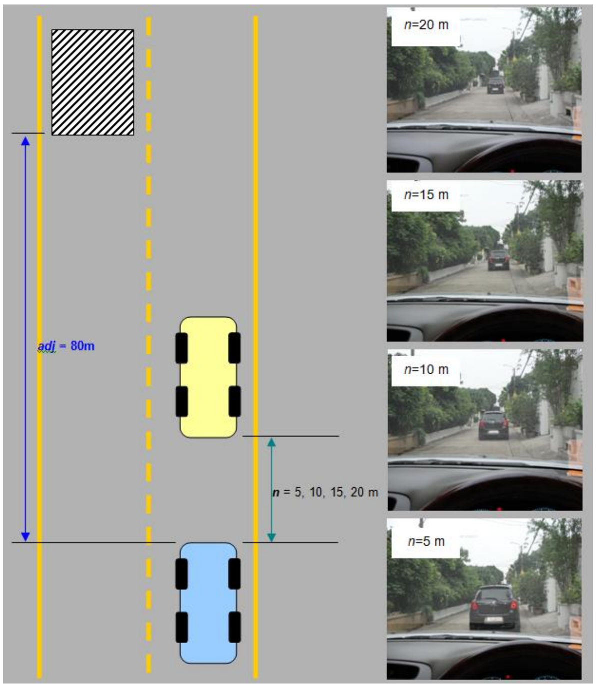



Fig. 3 The test for finding the upper limit of *n*

### 2.2 Camera and monitor

The selection of the camera and the monitor is important for the design of the prototype as they are two main hardware components of the system. For the camera, there are many types of cameras including a digital camera, a security camera, video camera etc. The video camera is chosen as it can record good quality and continuous motion images and can transmit these images to the monitor in a very short period of time. It also has a big range of focal lengths, i.e. zooming capability and the ‘night vision’ mode for recording night vision images in grayscale or greenish images. The field of view and image height and depth specifications are not given by the manufacturer so they have to determined by doing some experiments to make sure they are good for the showing the frontage blind spot. The monitor to be used has to match the resolution of the camera, be big enough for the driver to see the images, be able to install on top of the passenger-side front console. With the results from tests and questionnaires, a 7-inch LCD monitor is chosen.

### 2.3 Camera attachment position

The best possible position and offset for the installation of the camera is examined experimentally. The camera is attached to the front fender, near the side mirror, near the B-pillar, and on the side of the rear fender of Vehicle 1. The projected view of Vehicle 3 in the blind spot for the driver to overtake Vehicle 2 is best when the camera is on the side of the fender behind the C-pillar with an offset that should be as much as possible as shown in Fig. 4.

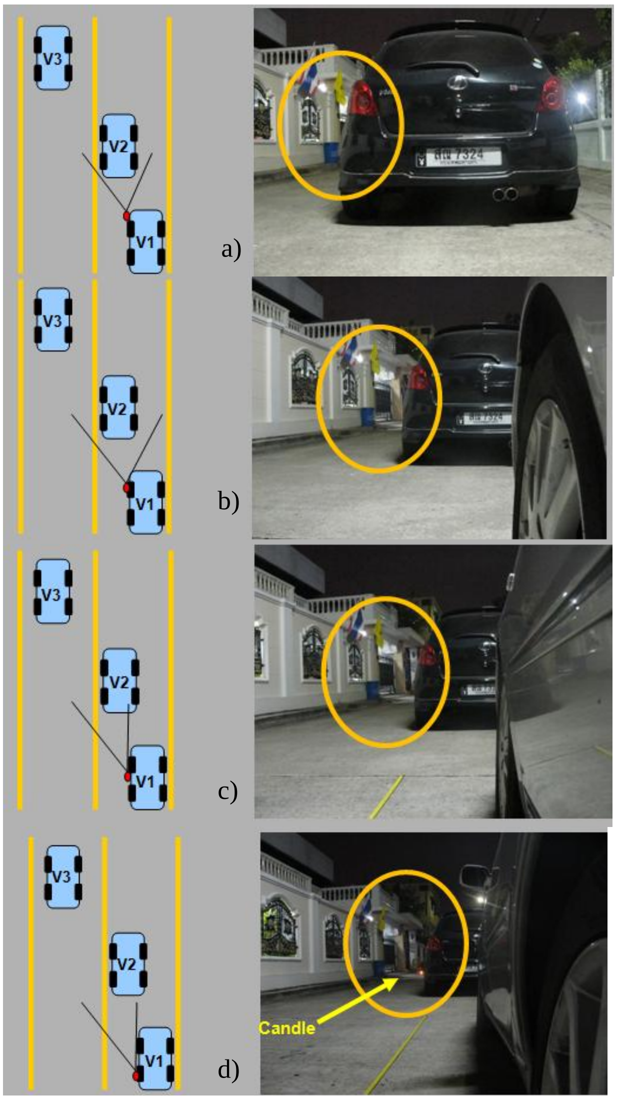



Fig. 4 Diagrams and camera images from various positions of a camera a) at the front fender, b) at the side mirror, c) at the B-pillar, and d) at the rear fender of the vehicle

Considering Fig. 4 a)-c), the camera only projects the vision of the front vehicle but not the candle (in place of Vehicle 3 for a clearer image results). Only the fourth position, at the rear fender, can show the candle in the picture.

### 2.4 Vision possibility and Necessity of rotation of camera

First, a variable is defined in addition to the first three in Section 2.1; ‘*a*’ is the distance from Vehicle 1 left edge to the left lane, shown in Fig 6. The position of the camera is on the rear fender of the car giving camera offset of 7.5 cm and the distance from the front to the camera $l$ = 4 m. With a standard lane width equal to 3 m, $x$ is 3+$a$.

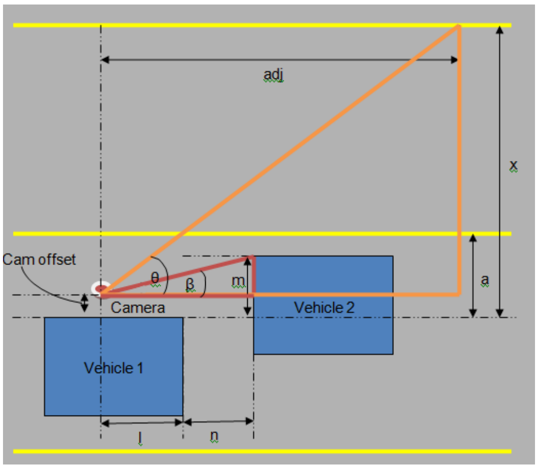


Fig. 5 Vision possibility modeling with variables

The geometry of the model in Fig. 5 is analyzed to predict the possibility of the camera vision for the cases where Vehicle 2 is further left to the left and almost out of the left lane. The camera has to see the leftmost area of the left lane, i.e. the view span must cover to distance *x*. Define the angles θ and β depicted in Fig. 6 and can be calculated by

$$\theta = \tan^{-1} [(x - \text{Cam offset}) / adj] \tag{1}$$

$$\beta = \tan^{-1} [(m - \text{Cam offset}) / (l+n)] \tag{2}$$

According to Fig. 5 and Eqs. (1) and (2), the possibility of camera vision can be decided by comparing the angles θ and β. If θ > β, then the camera can see Vehicle 3. To be able to see or not also depends on *m* and *n*, thus several conditions (heavy, medium, and light traffic; small, moderate, and large lateral offset) are applied, and listed along with their possibility to see Vehicle 3 in Table. 1. To reduce the number of cases to analyze, the cases where *m* is negative are not included in the analysis because when the obstructing vehicle is moved to the right relative to the driving vehicle, the vision barrier is much reduced.

According to results obtained from calculations from the equations in Table.1, it is discovered that theoretically there is very high chance that the camera can view the blind spot to a safety distance provided that the camera must have a good resolution at the safety distance at 80 m. Note that the real situation tests are also performed to verify the above theoretical results. The real situation test results are shown in Table. 2.

Table. 1 Camera vision possibility for several driving conditions (Y = yes = be able to see)

| Case | *a* (m) | *x* (m) | *m* (m) | *n* (m) | θ > β |
|---|---|---|---|---|---|
| 1 | 0.00 | 3.00 | 0.00 | 2-17 | Y |
| 2 | 0.37 | 3.37 | 0.37 | 2-17 | Y |
| 3 | 0.37 | 3.37 | 0.00 | 2-17 | Y |
| 4 | 0.73 | 3.73 | 0.73 | 2-8.2 | Y |
| 5 | | | | 8.3-11 | |
| 6 | | | | 11.1-17 | Y |
| 7 | 0.73 | 3.73 | 0.37 | 2-17 | Y |
| 8 | 0.73 | 3.73 | 0.00 | 2-17 | Y |
| 9 | 1.10 | 4.10 | 1.10 | 2-2.4 | Y |
| 10 | | | | 2.5-3.3 | |
| 11 | | | | 3.4-8.2 | Y |
| 12 | | | | 8.3-17 | |
| 13 | 1.10 | 4.10 | 0.73 | 2-8.2 | Y |
| 14 | | | | 8.3-9.6 | |
| 15 | | | | 9.7-17 | Y |
| 16 | 1.10 | 4.10 | 0.37 | 2-17 | Y |
| 17 | 1.10 | 4.10 | 0.00 | 2-17 | Y |
| 18 | 1.46 | 4.46 | 1.46 | 2-5.1 | |
| 19 | | | | 5.2-8.2 | Y |
| 20 | | | | 8.3-17 | |
| 21 | 1.46 | 4.46 | 1.10 | 2-8.2 | Y |
| 22 | | | | 8.3-15.6 | |
| 23 | | | | 15.7-17 | Y |
| 24 | 1.46 | 4.46 | 0.73 | 2-8.2 | Y |
| 25 | | | | 8.3-8.5 | |
| 26 | | | | 8.6-17 | Y |
| 27 | 1.46 | 4.46 | 0.37 | 2-17 | Y |
| 28 | 1.46 | 4.46 | 0.00 | 2-17 | Y |

### 2.4.1 Fixed or rotating camera testing

The rotating and fixed camera system is taken into concern for its maximum efficiency in the situation where the orientation of the driver's vehicle is not in line with the vehicle in front. In addition, to ensure the calculation is correct and accurate, the real-situation tests must be conducted. The tests are done for every case in Table. 1 with various camera angles from 0 to 20 degrees and some of their results are illustrated in Fig. 6.

From Fig. 6, it is noticed that even though as the camera angle increases from 0 to 20 degrees just making Vehicle 3 in the image move to the right, it does not give a better vision of the blind spot. This is because the angle of view of the camera is broad enough and thus rotating the camera will not help fetching more images from the blind spot. Therefore, the fixed camera is chosen for its simplicity and durability with an edge over a small improvement in visibility if any. The camera angle is chosen to be about 20 degrees as the image shows some small area of the left side of Vehicle 1 for the driver's reference point.

### 3. Performance Test Set-up and Results

The prototype of the system is fully tested whether it can resolve the blind-spot problem enhancing the driving safety and whether its performance is superior to the vision from the passenger. The tests were done on a real situation with various cases of traffic condition, lateral offset *m* and distance between Vehicles 1 and 2 *n* listed in Table. 1. The camera and the monitor are installed into Vehicle 1 depicted in Fig. 7.


a)


b)


c)

Fig. 6 Images in several camera angles a) Case 1, b) Case 4, and c) Case 18

Fig. 7 System set-up on Vehicle 1

Due to the safety concerns and conveniences in data collection, the tests were conducted on stationary cars on the real road. Note that the system was also tested on the real traffic with moving cars and it works relatively well.

The first full performance test has Vehicle 1 a Toyota Camry, Vehicle 2 a Toyota Yaris, and Vehicle 3 a Toyota Vigo. The results of Cases 1, 24 and 26 when *n* = 2, 7, 12, and 17 m are shown in Figs. 8 and 9 below. The top left image is the orientation view. The top right image is the driver's vision. The bottom left image is that from the camera/monitor. And the bottom right image is the passenger's vision.

It can be observed from Fig. 8 that in some positions a), c) and d), the driver cannot see Vehicle 3; however, the passenger and camera can detect Vehicle 3 in all positions. From Fig. 9, the driver cannot see Vehicle 3 in a) and c). The passenger and the camera can see Vehicle 3 for all values of *n*. The test results are summarized in Table. 2 indicating whether the driver, the passenger, and the camera can see Vehicle 3 or not.

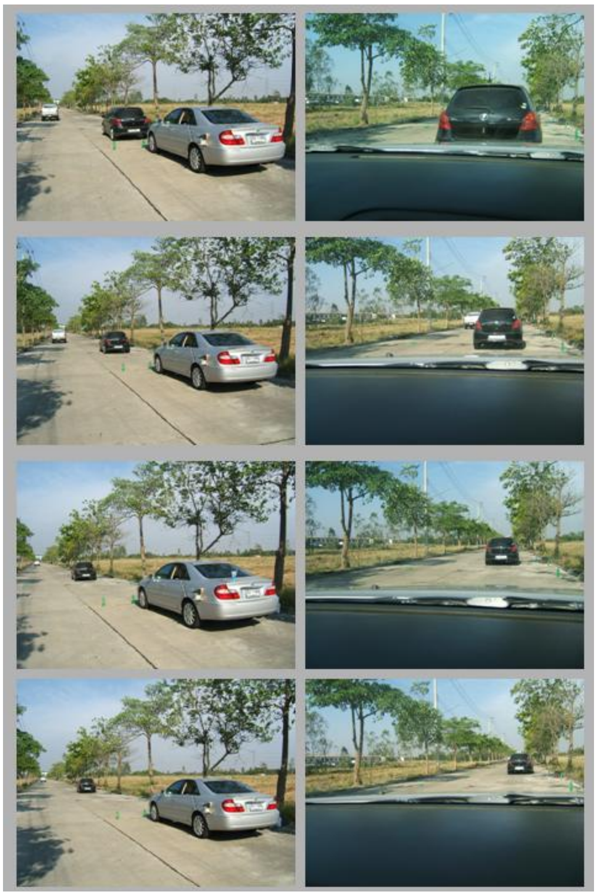

a)


b)


c)


d)

Fig. 8 Test images of Case 1 with various gap distances $n$ a) $n$ = 2 m, b) $n$ = 7 m, c) $n$ =12, and d) $n$ = 17



a)

b)

c)

Fig. 9 Test images of Cases 24 and 26 with various gap distances *n* (*n* = 2, 7, 12, and 17) a) the driver's vision, b) the passenger's vision, and c) camera vision

Table. 2 Summary of driver, passenger, and camera's visibility from real situation test (D = driver visibility, P = passenger visibility, and C = camera visibility; Y = Good visibility)

| Case | *a* (m) | *x* (m) | *m* (m) | *n* (m) | D | P | C |
|---|---|---|---|---|---|---|---|
| 1 | 0.00 | 3.00 | 0.00 | 2 | | Y | Y |
| | | | | 7 | Y | Y | Y |
| | | | | 12 | | Y | Y |
| | | | | 17 | | Y | Y |
| 2 | 0.37 | 3.37 | 0.37 | 2 | | Y | Y |
| | | | | 7 | Y | Y | Y |
| | | | | 12 | | | Y |
| | | | | 17 | | Y | Y |
| 3 | 0.37 | 3.37 | 0.00 | 2 | Y | Y | Y |
| | | | | 7 | Y | Y | Y |
| | | | | 12 | | Y | Y |
| | | | | 17 | Y | Y | Y |
| 4-6 | 0.73 | 3.73 | 0.73 | 2 | | | Y |
| | | | | 7 | Y | Y | Y |
| | | | | 12 | | Y | Y |
| | | | | 17 | | | Y |
| 7 | 0.73 | 3.73 | 0.37 | 2 | | Y | Y |
| | | | | 7 | Y | Y | Y |
| | | | | 12 | | Y | Y |
| | | | | 17 | Y | Y | Y |
| 8 | 0.73 | 3.73 | 0.00 | 2 | Y | Y | Y |
| | | | | 7 | Y | Y | Y |
| | | | | 12 | Y | Y | Y |
| | | | | 17 | Y | Y | Y |
| 9-12 | 1.10 | 4.10 | 1.10 | 2 | | | Y |
| | | | | 7 | | Y | Y |
| | | | | 12 | | | Y |
| | | | | 17 | | | |
| 13-15 | 1.10 | 4.10 | 0.73 | 2 | | | Y |
| | | | | 7 | Y | Y | Y |
| | | | | 12 | | | Y |
| | | | | 17 | | Y | Y |
| 16 | 1.10 | 4.10 | 0.37 | 2 | | Y | Y |
| | | | | 7 | Y | Y | Y |
| | | | | 12 | | Y | Y |
| | | | | 17 | Y | Y | Y |
| 17 | 1.10 | 4.10 | 0.00 | 2 | Y | Y | Y |
| | | | | 7 | Y | Y | Y |
| | | | | 12 | Y | Y | Y |
| | | | | 17 | Y | Y | Y |
| 18-20 | 1.46 | 4.46 | 1.46 | 2 | | | |
| | | | | 7 | | | |
| | | | | 12 | | | |
| | | | | 17 | | | |
| 21-23 | 1.46 | 4.46 | 1.10 | 2 | | | |
| | | | | 7 | Y | Y | Y |
| | | | | 12 | | | |
| | | | | 17 | | | |
| 24-26 | 1.46 | 4.46 | 0.73 | 2 | | Y | Y |
| | | | | 7 | Y | Y | Y |
| | | | | 12 | | Y | Y |
| | | | | 17 | | Y | Y |
| 27 | 1.46 | 4.46 | 0.37 | 2 | | Y | Y |
| | | | | 7 | Y | Y | Y |
| | | | | 12 | | | |
| | | | | 17 | | Y | Y |
| 28 | 1.46 | 4.46 | 0.00 | 2 | Y | Y | Y |
| | | | | 7 | Y | Y | Y |
| | | | | 12 | | Y | Y |
| | | | | 17 | Y | Y | Y |

By counting number of cases of good visibility, it can be seen from the results that among all cases the driver, the passenger, and the camera can see Vehicle 3 for 41%, 73%, and 85%, respectively. As such the frontage camera system can extend the driver's vision by 44% and passenger's vision by 12% of the cases. Additional tests were performed when the obstructing car, Vehicle 2, is a bigger size (a Toyota Vigo). The results are as expected that the capability to see Vehicle 3 in the blind-spot is less with the driver, the passenger, and the camera vision.

## 4. Conclusion

The prototype of Frontage Camera System consisting of a camera and a monitor is designed to be installed in a car to help eliminating the frontal blind spot. After the prototype of the frontage camera system is built and tested for its performance, the system can show the frontage blind spot 85% of the time, which is very satisfactory. When comparing the system performance to the driver's and passenger's visions, it also displays a great satisfaction. First considering the passenger's vision, the system gave an increase in vision of around 12%. Similarly, the system gave an increase of approximately 44% of the cases from the driver' vision. With a bigger car in front, the system helps the driver much more as the driver's vision is much reduced because of the large size of the obstructing car but the camera vision is affected a lot less.

Definitely, the frontage camera system is a promising system that provides more safety for the driver to overtake another vehicle as it shows the obstructing vehicle on the blind spot. However, the frontage camera system is by no means to replace the real visuals of the driver; it is meant to give an additional view of the front of the vehicle, which is usually a frontal blind-spot.

## 5. Acknowledgement

I would like to thank you Taychatum Sagul-chuang, Bundit Petchnukulkeat, V-kawin Jelatianranat, and Pornpong Pattanapirunhakit for their contributions in this project.

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