ESTIMATION OF OOP FROM CONDITIONAL PROBABILITIES OF AIRBAG FIRE-TIMES AND VEHICLE RESPONSE

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ABSTRACT

The airbag can fire at any given time during a crash. To qualitatively and quantitatively address the probabilistic nature of the airbag fire-time as a result of a crash, a statistical data based model was used. Two models were constructed: one was based on rigid barrier impacts and the other used offset deformable barrier impacts. These models were developed previously and some of the preliminary results were presented at the 1998 SAE conference in Detroit. Since that time the models have been refined by inclusion of additional data, and the results of the refined models were compared to the results from the previously constructed models. The models were used to address the effects of raising the "threshold velocity" and the risks of an occupant contacting the airbag module as a result of late firing. Although the individual numerical values have changed, the indicated general trends remain the same. Raising the "threshold velocity" may or may not decrease the number of occupants on the module, depending on the accuracy of NASS/CDS and fire/no-fire as a function of velocity (c-censor*), but it appears to reduce the effectiveness of the airbag when it does fire. The model indicates that decreasing the width of the c-censor, i.e., delta V from no fire to all fire, may be useful in reducing the number of occupants on the module without decreasing the effectiveness of the airbags.

* the term c-censor refers to censoring of the data in terms of airbag firing. To distinguish sensor from censor when speaking the term c-censor is used.

INTRODUCTION

A statistical model was developed to estimate the occupant position at the time the airbag fires in Ref. 1. Inputs to the model were: 1) the airbag fire-time probability surface representing the frequency of the probability of airbag fire-time as a function of time and impact velocity; 2) the occupant displacement distribution surface representing the displacement histories at any given velocity; 3) the accident distribution representing the accident percentage at any given velocity; and 4) the c-censor representing the airbag firing percentage at any given velocity. The outputs were the number of occupants at any given position at the time the airbag fires. This is a data based model and the surfaces and distribution curves mentioned above were constructed from data which were obtained from multiple sources, such as Insurance Institute for Highway Safety (IIHS), Transport Canada (TC), National Highway Transportation Safety Administration (NHTSA), and National Automotive Sampling System/ Crashworthiness Data System (NASS/CDS).

When the airbag fire-time probability surface, the occupant's displacement probability surface and the initial position distribution are developed, the model can then estimate the number of occupants at a given distance from the airbag module at any given impact velocity. This estimate is computed by using the accident distribution and a c-censor assumption. In the previous study, the accident distribution and the c-censor played important roles in determining the estimates of the number of occupants at any given distance from the module. As mentioned above, the accident distribution is objective, since it is obtained from collecting the accidents in the field. The c-censor characteristics are, however, variable. Its performance can be controlled through the airbag sensor algorithm. The effect of the c-censor performance on the number of occupants on the module when airbag fires is also investigated in this study. It is believed that this study provides some theoretical basis that may be useful in estimating a preliminary aspects of airbag sensor performance in the field.

The following conclusions were drawn from the previous paper [1]. 1) A later airbag firing will result in more occupants on the module when the airbag fires. 2) The model developed from the rigid barrier impacts indicates that it is unlikely that the occupants will contact the airbag module when the airbag fires. 3) The effects of changing the "threshold velocity" is indeterminate, because threshold is poorly defined. 4) The effect of changing c-censor velocity distribution for the airbag depends on the number of crashes at a given velocity and the probability of firing for all velocities. 5) The effect of tightening the band of the c-censor velocity distribution may be useful in decreasing the number of occupants on the module without decreasing the effectiveness of the airbag.

We anticipated that the results predicted in [1] would change once a significant amount of new airbag fire-time data became available. This was thought probable because new data would affect the construction of the airbag fire-time distribution surface. With the new data, although some changes were noted, the overall conclusions were similar. The later the airbag fires, the more occupants will be on the module at the instance of airbag firing. The trends of the number of occupants on the module as a function of increasing the c-censor velocity or shifting the accident distribution curve are the same as those in the previous paper [1]. In addition, this paper provides an estimate of the number of occupants on the module for different initial seating positions, i.e. the distance from the airbag module. These results are applicable to the occupants on both driver and passenger sides.

METHOD

The method used in this paper is the same as the one used in [1]. In order to get the estimated number of occupants at a given distance from the module, the airbag fire-time probability surface, the occupant's displacement surface, occupant's initial position distribution, the accident distribution curve, as well as the c-censor are necessary. The airbag fire-time probability surface is constructed by curve fitting techniques. For each velocity, the parameters for the best fit of a chosen function are obtained. The parameters of the fitting function family are then used to generate a surface. The occupant displacement surface is constructed by using a simple analytical model and the vehicle displacements. The simple analytical model treats the occupant as a free moving point mass while the vehicle decelerates. The occupant's initial position distribution and its standard deviation were obtained from TRW, IIHS and the University of Michigan Transportation Research Institute. The accident data were collected from the NASS/CDS. The data were then used to define a distribution function through a curve fitting technique. The c-censors, which are defined as the percentage of airbags that fire at a given velocity, illustrate the probabilistic nature of whether the airbag fires at that given velocity. The c-censors can be constructed using frontal barrier impact test data or offset test data. However, this may not represent the real world conditions. The reason is that even for the same type of impact tests conducted in the laboratory, different c-censors can be obtained for different cars. Crashes in the field are much more complicated. They consist of uncountablely different types of crashes with a wide variety of vehicles.

The model uses the airbag fire-time surface, occupant displacement surface, their standard deviations and the occupant's initial seating position to produce the probability that the occupant is at a given position or less from the airbag module. This probability includes the possibility of occupants' contacting the module when the airbag does not fire. The process of censoring the data will remove the effect of the airbag not firing. The estimation of the number of occupants on the module can then be finally determined by including the accident distribution.

Since the publication of the last paper, additional airbag fire-time data have been obtained. The data are for 25 mph, 35 mph, and 40 mph offset impacts. New fire-time data for 40 mph offset tests exhibit a distribution similar to the data used in the previous paper. However, fire-time distribution characteristics for the 35 mph and 25 mph show some differences. Efforts have been made to find another fitting function family. However, the lognormal function is still found to be the best fit. Figures 1a, 1b, 2a and 2b show those differences. Due to an insufficient amount of data used in 25 mph offset tests in the

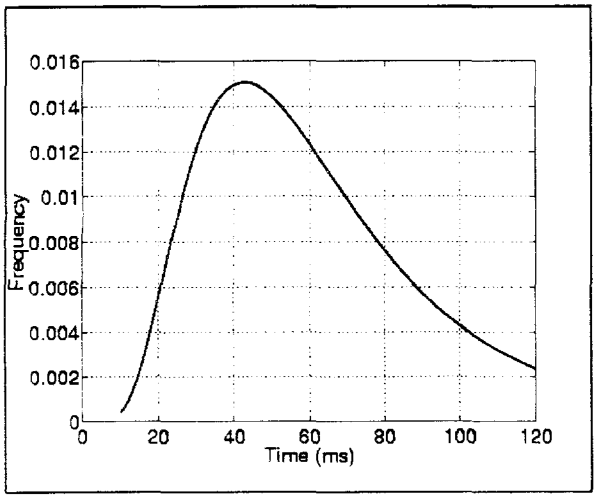

Figure 1a: Airbag fire-time for 25 mph offset impacts using previous data

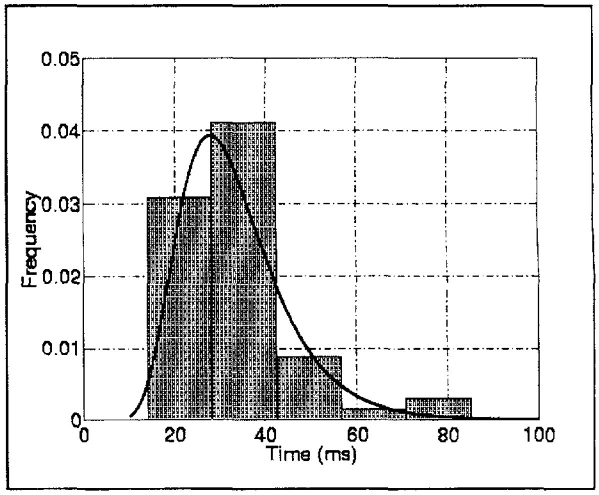

Figure 2a: Airbag fire-time for 35 mph offset impacts using previous data

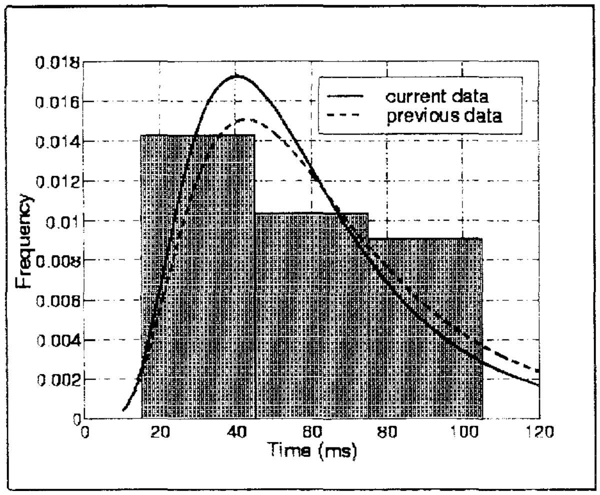

Figure 1b: Airbag fire-time for 25 mph offset impacts

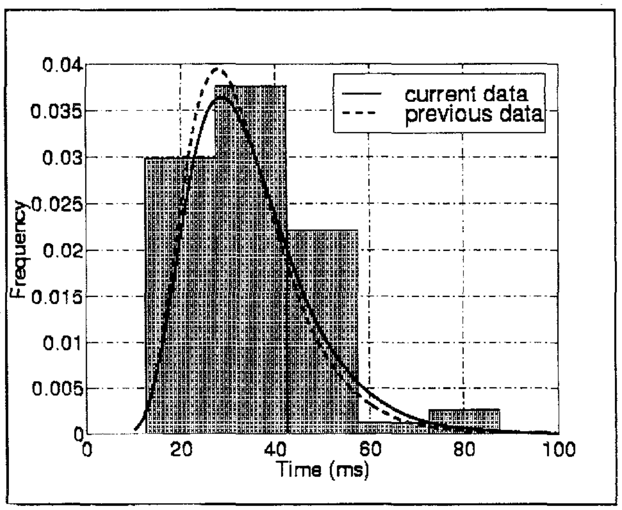

Figure 2b: Airbag fire-time for 35 mph offset impacts

previous paper, the histogram could not be constructed properly. Figures 2a and 2b indicate that the 35 mph fire-time distribution is similar to the previous results, however, there are some differences in the shape and peak. The figures also indicate that the most probable fire-time for 35 mph offset tests is around 27 or 28 ms. The times when peaks occur for the 25 mph offset impacts show the differences for both sets of data. The old set of data indicates that the most frequent fire-time is 43 ms, while it is 39 ms for the new set of data, which indicates that there are less late firings.

In order to estimate the number of occupants at a given position, the accident distribution curve and the c-censors are required by the model. The accident distribution and c-censors which have been used in [1] will be used in this paper. As shown in [2], it is possible that NASS/CDS underestimates the velocity in the accident distribution to some degree. To evaluate this effect, the accident distribution is parallel transported, i.e., shifted, by +3 mph.

Figure 3 shows the accident distribution curve and its shifted curve. A sum of Hyperbolic functions were used to fit the accident distribution. The shifted accident curve will be used to illustrate the influence of underestimation on the number of occupants on the module. Four c-censors are shown in Figure 4 which were designed in an attempt to capture the variation of real world fire/no-fire probability. It can be seen that those c-censors have different cut off times for no airbag firing and all airbag firing times. Field estimated c-censor #1 is an attempt to capture fire/no-fire distribution in the field. It has a wider range in velocities from no fire (7 mph) to all fire (20 mph) than that from the barrier impacts. Field estimated c-censor #2 is based on field estimated c-censor #1, but it has a higher all fire velocity of 25 mph. Barrier estimated c-censor is based on the data

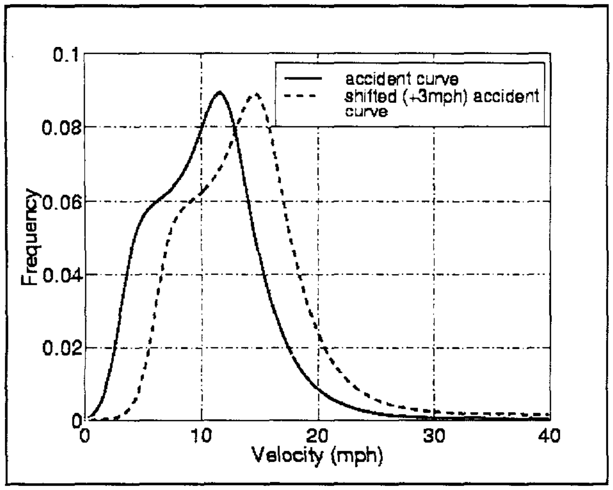

Figure 3: Accident density as a function of impact velocity

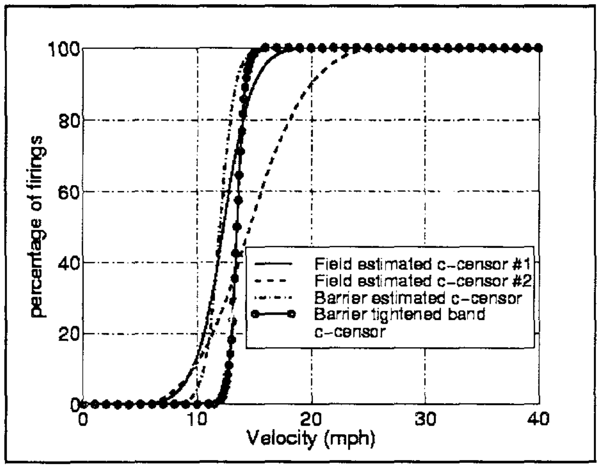

Figure 4: Four c-censors used in the study

from frontal rigid barrier impact tests. It has a narrower band of velocities from no fire to all fire compared to the Field estimated c-censors. The Barrier tightened band c-censor was constructed to see the effect of raising no fire velocity while keeping all fire velocity the same.

RESULTS

The influences of the accident distributions, the fire/no-fire c-censors, as well as occupant's initial seating positions have been investigated in this study. In the previous paper, it was found from the model developed for the rigid barrier impacts that it is unlikely that any occupant will contact the airbag module when the airbag fires and the same results were found with the additional data. Therefore, the following results are only for the offset type crashes with unbelted occupants. It should be mentioned that the term raising "threshold velocity" by +2 mph, as used in this paper, means parallel transporting of the c-censor velocity by +2 mph.

Figure 5 shows the percentage of occupants on the module as a function of impact velocity. It should be noted that the mean fire-times in data sets [1] are

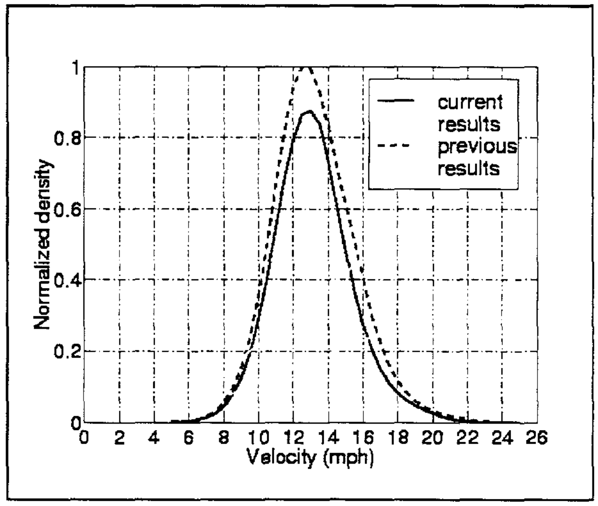

Figure 5: Normalized density of the occupants on the module

later than those shown in the new data sets. The results based on the previous data sets indicate that there will be more occupants on the module when the accident distribution and the c-censor assumptions remain the same. The figure also shows that the velocity at which the peak occurs is higher with the current data sets than that with the previous data.

To determine the effect of changing the c-censor on the occupant assessment values for the 50th percentile "in position" male occupants, over 200 crash simulations were run using MADYMO V5.2. More simmulations were conducted in this study than that in the previous study. These simulations include 30 mph, 14 mph rigid barrier impacts and 40 mph, 35 mph, and 25 mph offset impacts. At each impact velocity, three different vehicle configurations were simulated, representing small, medium, and large vehicles. Some vehicle simulations were run with two different airbag configurations and some were run with three different airbag configurations. The results of these simulations are summarized in Table 1, which shows that the range of the assessment values increases compared to the previous study. Although the results presented are different from the previous results [1], the trends are the same.

As mentioned in the previous section, the c-censor and the accident distribution are important for estimating the number of occupants at a given distance from the airbag module. A complete tabulation of results for the effects of the c-censor and the accident distribution on the number of occupants on the module is presented in Tables 2 to 4.

Table 1. Increase of assessment values as a result of parallel transporting c-censor by +2 mph

HIC		Chest		
15ms	30ms	Acc. (G's)	Compression (in)	travel (in)
50~300	50~500	0~21	0.1~0.6	0.1 ~2

Column 1 of Table 2 shows the number of occupants on the module at the initiation of airbag deployment for each of the 4 c-censors. The results are non-dimensionalized by the results obtained for the "field estimated c-censor #1", which the model estimates to be in the range of 200 to 600 occupants. The second data column of Table 2 shows similar results for the case where the c-censor velocity distribution values for each of the c-censors was parallel transported by +2 mph. The data here was normalized by the corresponding numerical results from the first column. The table shows that the number of occupants on the module for all the c-censors are reduced when the c-censor velocity is raised. The "barrier tightened band c-censor" shows the greatest reduction. It should be noted that the total HARM may not necessarily be reduced if the results shown in Table 1 are also considered.

Table 2. Percent of of occupants on the module due to effect of parallel transporting c-censor by +2 mph

	percent with respect to field c-censor#1	resulting percent by parallel transporting c-censor by +2 mph
field estimated #1	100%	71%
field estimated #2	57%	80%
barrier estimated	99%	73%
barrier tightened band	49%	47%

As was noted in the previous section, the accident rate was expressed as a function of velocity based on the NASS/CDS data. The model then was used to determine the sensitivity of the results to the variation in the NASS/CDS impact velocity estimates. Table 3 shows the number of occupants on the module using the accident density curve obtained by shifting the curve, as shown in Figure 3, by +3 mph, i.e. adjusting the data as if the NASS/CDS velocities were consistently underestimated by +3 mph. For reference, the data in the first column of Table 2 is taken and the second column is again normalized by the corresponding numerical results from the first column. The results show that the number of occupants on the module are significantly increased when the accident density curve is shifted to the right, i.e. if the NASS/CDS impact velocities were considered to be underestimated.

Table 3. Percent of occupants on the module due to the effect of shifting the accident density by +3 mph

	percent with respect to field c-censor #1	resulting percent by shifting accident density by +3 mph
field estimated #1	100%	133%
field estimated #2	57%	134%
barrier estimated	99%	134%
barrier tightened band	49%	183%

Table 4 shows similar results for the case where the accident density curve is shifted by +3 mph (as in Table 3) and the c-censor velocity distribution is parallel transported by +2 mph (as in Table 2). The reference data in the first column is from Table 3, and the data in the second column is again normalized by the corresponding numerical results from the first column. The results in the second column show that although again the numbers are

Table 4. Percent of occupants on the module due to the effects of both shifting accidents density by +3 mph and changing c-censor by parallel transporting +2 mph

	resulting by shifting accident curve by +3 mph	resulting percent by both shifting accident density by +3 mph and parallel transporting c-censor V by +2 mph
field estimated #1	133%	94%
field estimated #2	134%	98%
barrier estimated	134%	96%
barrier tightened band	183%	70%

reduced by changing the c-censor velocity, the reduction in this case is much less than that shown in Table 2. Therefore, it is possible that the number may actually increase if the accident density is underestimated by some value more than +3 mph.

To facilitate comparison of the results from the previous and the current model, Table 5 presents again the data shown in Tables 2, 3, and 4, respectively, together with the additional corresponding data from the previous study. A review of the Table 5 shows that the trends indicated by both the old and current model are the same, even though individual values have changed.

The effect of the occupant's initial positions on the number of occupants on the module is shown in Figure 6a and Figure 6b. It is assumed that each initial position is not exact. Instead, there is a Gaussian distribution with the initial positionn representing the mean value. Two types of initial position distribution are considered: one has its standard deviation of 1 mm which means that the population sits very close to the position of a given x-value. The other is with a standard deviation 50 mm which means all the population sits on the average at the position of a given x-value, but some will sit behind and some will sit in front of that average position. The figures show that the number of occupants on the module are continuously decreasing as the mean initial distance from the module increases. If an occupant initially sits 700 mm or more away from the airbag module, it is, as a results of late firing, almost impossible for the occupant to be on the module when the airbag fires.

The results in Figure 6a are obtained by using Field estimated c-censor #1 and those in Figure 6b by Field estimated c-censor #2. For a given mean initial position, a higher value of standard deviation will give a greater number of occupants on the module.

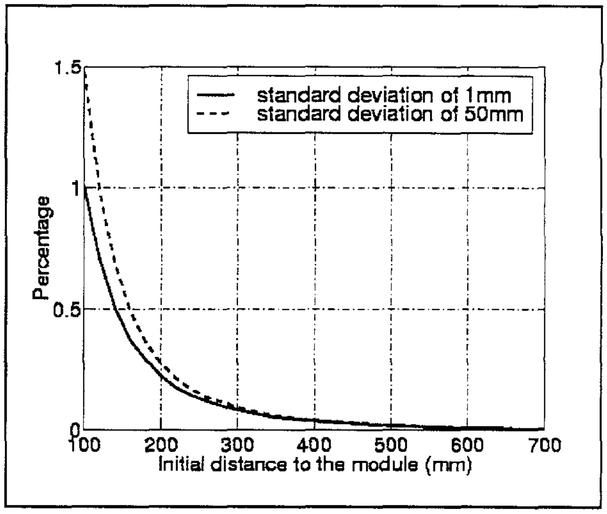

Figure 6a: Percentage of the occupants on the module using Field estimated c-censor #1

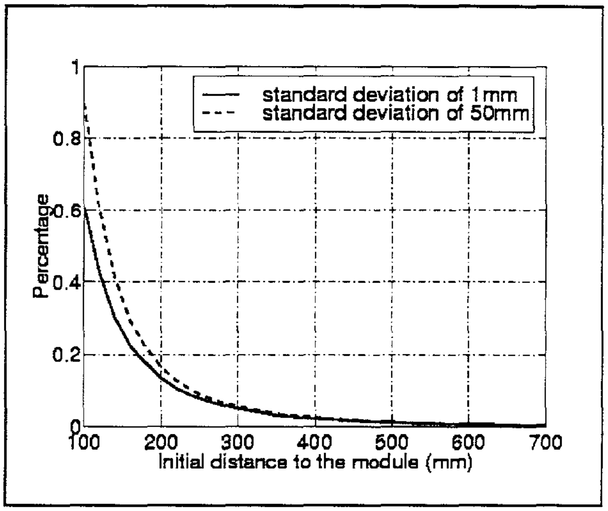

Figure 6b: Percentage of the occupants on the module using Field estimated c-censor #2

Table 5. Comparison of the percent of occupants on the module between current and previous results

	percent with respect to field c-censor #1 (current,previous)	resulting percent by parallel transporting c-censor by +2 mph (current,previous)	resulting percent by shifting accident density by +3 mph (current,previous)	resulting percent by both shifting accident density by +3 mph and parallel transporting c-censor V by +2 mph (current, previous)
field estimated #1	100% ,100%	71% , 70%	133%, 120%	94%, 92%
field estimated #2	57% , 56%	80% , 75%	134%, 129%	98%, 87%
barrier estimated	99% , 99%	73% , 80%	134%, 120%	96%, 97%
barrier tightened band	49%, 56%	47% , 52%	183%, 150%	70%, 77%

Field estimated c-censor #2 gives a significantly lower number of the occupants on the module compared to Field estimated c-censor #1. For example, if the average initial seating position for the small females is 270 mm from the module, the percentages of such occupants on the module are 0.12 (with standard deviation of 50 mm) and 0.1 (with standard deviation of 1 mm) for the c-censor #1. If the c-censor #2 is used, those percentages will be 0.074 (with standard deviation of 50 mm) and 0.064 (with standard deviation of 1 mm), respectively.

These figures can also be used to estimate results for occupant groups of various sizes. If the mean position and standard deviation are known, the percentage of the number of occupants on the module can be computed. For example, if the small occupants sit at a mean initial position of 270 mm, then the percentage of the number of the small occupants on the module can be considerably greater than that for the 50th percentile males who sit at a distance of 400 mm. In addition, similar estimation can be made for the occupants on the passenger side.

Figures 7a, 7b and 7c show that raising the c-censor "threshold velocity" decreases the *number* of occupants on the module. In Figure 7a, the probabilities are obtained from the airbag fire-time surface, occupant displacement surface and occupant's initial positions. However, the results are obtained without considering the accident distribution and the c-censor. The probabilities in Figure 7b, labeled "the probability with accident curve", are the

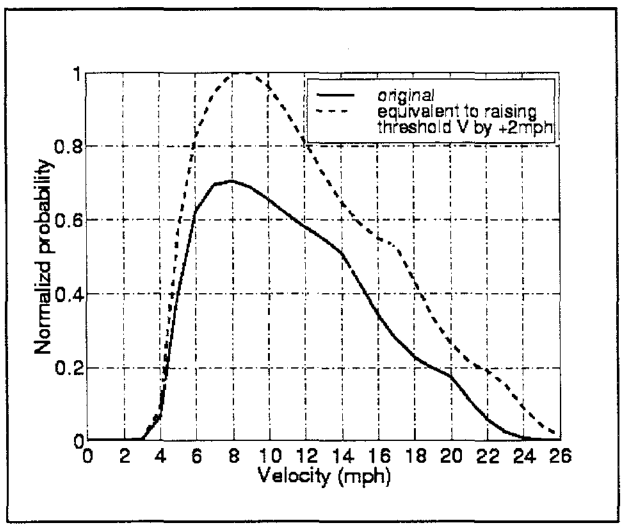

Figure 7a: Probability of the occupants on the module

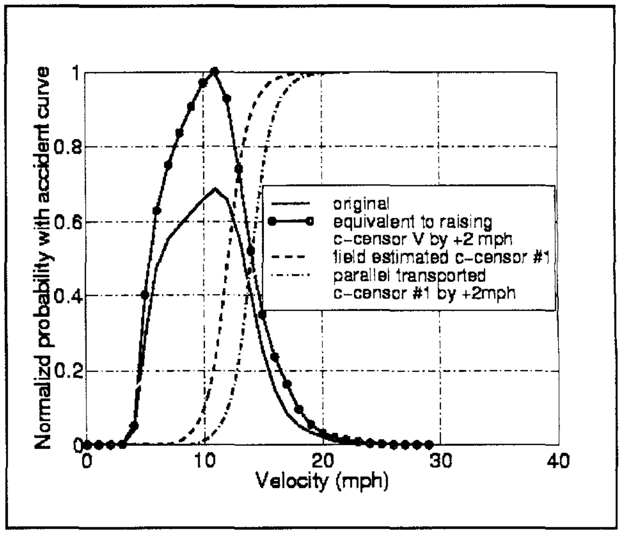

Figure 7b: Probability (with accident curve) of the occupants on the module and Field estimated c-censor #1

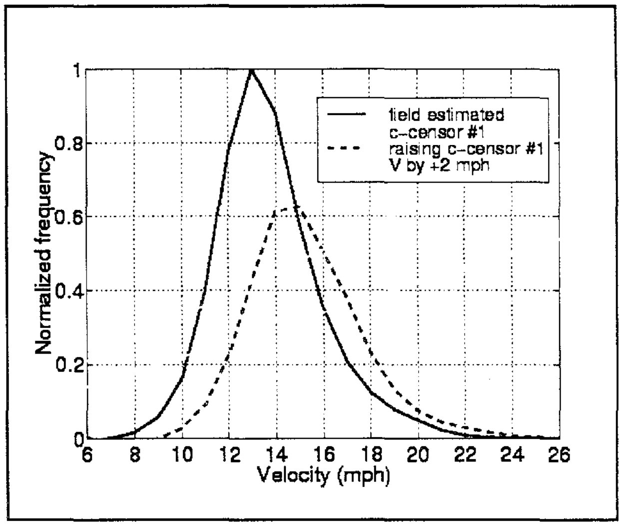

Figure 7c: Normalized density of occupants on the module using Field estimated c-censor #1

probabilities in Figure 7a multiplied by the accident distribution curve at each corresponding velocity. As the "threshold velocity" is increased, two factors will affect the number of occupants on the module. One is the fire-time distribution as a function of velocity. This factor tends to increase the probability of the number of occupants on the module because its effect is equivalent to later firing. Therefore, this probability increases as shown in the Figure 7a.However, the other factor, parallel transporting the c-censor in the direction of increasing the velocity, tends to decrease the *number* of occupants on the module. By parallel transporting the c-censor velocity by +2 mph, as shown in Figure 7b, the number of no fires increases, and hence, the number of the occupants on the module are significantly reduced when the airbag fires. The multiplication of the two curves, i.e., the probability with the accident curve and the c-censor curve, is shown in Figure 7c. It indicates that the numbers from raising the "threshold velocity" are less than that from without raising the "threshold velocity".

Figures 8a and 8b show the effect of accident distribution on the number of occupants on the module. The curve with the solid line represents the probability multiplied by the original accident distribution, while the curve with the dashed line represents the probability multiplied by the shifted (by +3 mph) accident distribution. It can be seen that the probability with shifted accident distribution shows greater area under the normalized probability-velocity curve. This results in a greater total number of occupants on the module after multiplying the c-censor values at corresponding velocities (Figure 8b).

It should be noted that raising c-censor velocity by +2 mph will not always reduce the number of occupants on the module. Figures 9a and 9b illustrate a case where raising the c-censor velocity by +2 mph will increase the number of occupants on the module. In this case, the accident distribution is

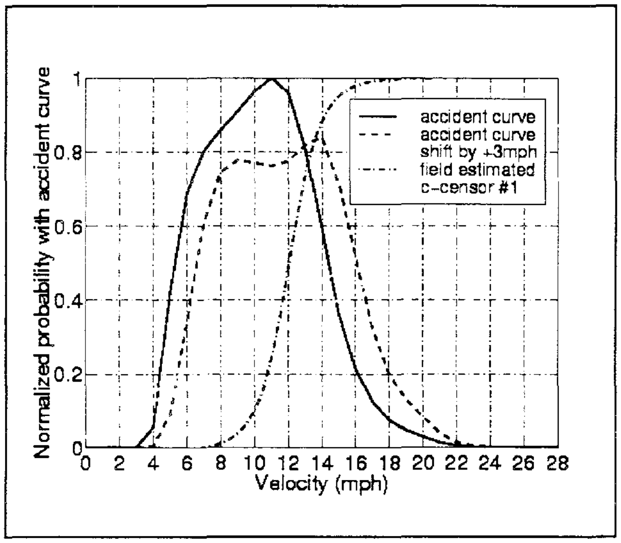

Figure 8a: Probability with accident curve of the occupants on the module and Field estimated c-censor #1

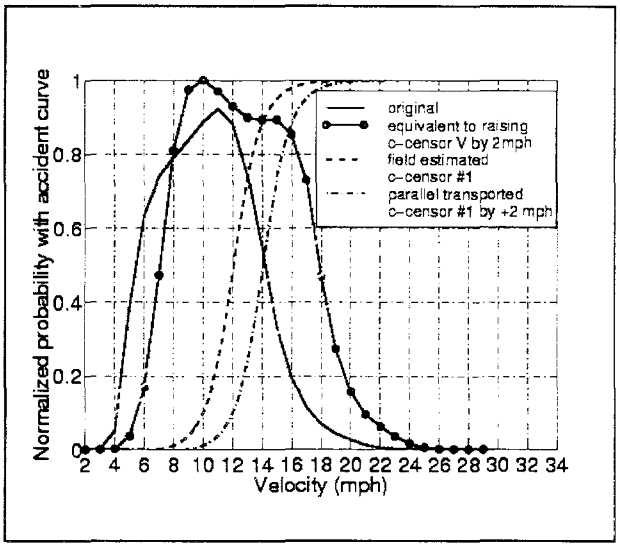

Figure 9a: Probability with accident curve of the occupant on the module and Field estimated c-censor #1

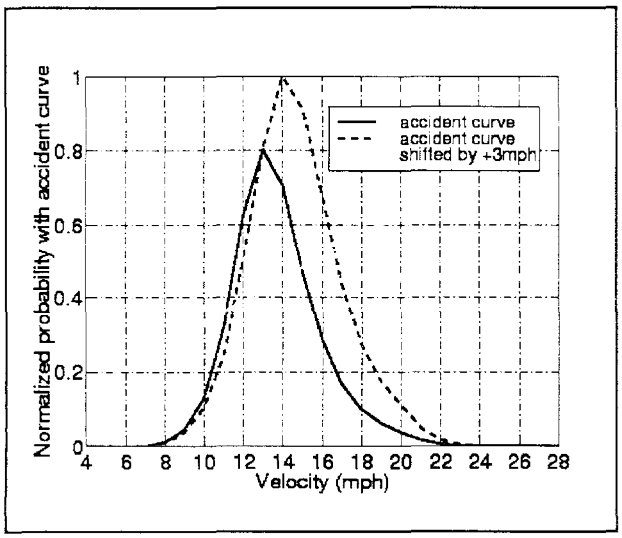

Figure 8b: Normalized density of the occupants on the module using Field estimated c-censor#1

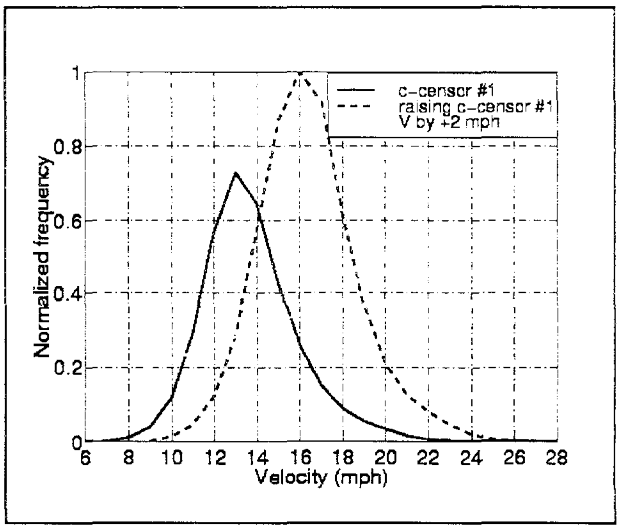

Figure 9b: Normalized density of the occupants on the module using Field estimated c-censor #1

shifted, i.e., parallel transported by +4 mph. Figure 9a shows that after the multiplication of the accident distribution, the probability with shifted accident distribution results in higher peak values, a longer duration of peak values, i.e. from 10 mph to 16 mph, and the average velocity is higher. Because of this, raising c-censor "threshold velocity" by +2 mph may increases the number of occupants on the module, as shown in Figure 9b.

DISCUSSION

The general solution process is to construct a model from functions of: the airbag fire-time probability and occupant displacement probability surfaces, accident distribution and c-censors. The model can then be exercised to estimate the number of occupants at a given distance from the module when the airbag fires. In addition, the effects of potential inaccuracy in the accident-velocity distribution, and different c-censors on that estimate can be analyzed. For example, if it is assumed that the airbag fire-time probability surface for the offset barrier impacts is an accurate estimate of the real-world crashes, then estimates of the number of people making contact with the module can be made. However, the results depend on the data used to construct both the fire-time probability and occupant displacement surfaces as well as the accident distribution and the c-censor. Additional or different data could significantly change the results. For example, if a significant amount of impacts are added with late fire-times, then the model will predict more occupants on the module.

The effects of the accident distribution and the c-censor on the number of occupants on the module were demonstrated previously [1]. Raising the "threshold velocity"(parallel transporting of the c-censor) by +2 mph can decrease or increase the number of occupants on the module depending on the accident distribution. Figure 10 represents the probabilities after processing with c-censors, which means those probability curves multiplied by the accident curves will produce the number of occupants on the module. It indicates that if the velocity for peak frequency occurring in the accident distribution is less than or equal to 15 mph, raising the "threshold velocity" could reduce the number of occupants on the module. However, if that velocity is greater than or equal to 16 mph, raising the "threshold velocity" by +2 mph may increase the number of occupants on the module. Once the airbag fire-time surface and the c-censor are determined, the accident distribution is the dominant factor in deciding the effect of raising the "threshold velocity" by +2 mph.

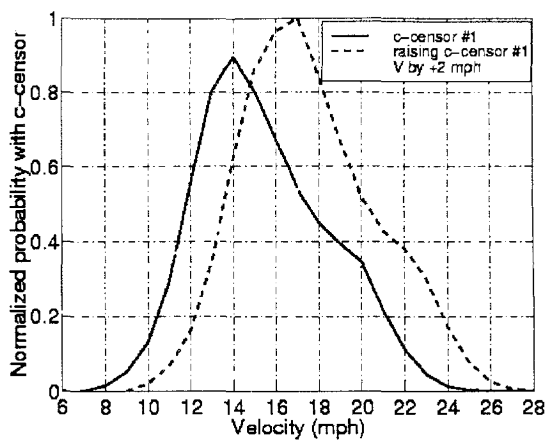

Figure 10: Probability with field estimated c-censor #1 of the occupants on the module

The conditions controlling the determination of when and if the airbag will fire were developed using rigid barrier frontal impacts at different velocities. The velocity dependent censoring of the airbag firing used in our model is defined by the barrier estimated c-censor. Observation from our results indicates that the barrier c-censor, when tightened always results in a fewer number of occupants on the module regardless of whether the accident distribution is underestimated or not . Figure 11 illustrates this result. This is because the values from the barrier estimated c-censor are always greater than the values from the barrier tightened c-censor. As a result, if the c-censor is tightened, it reduces delta v from no fire to all fire. By raising the no fire level, the number of occupants on the module could be significantly reduced without the potential for losing the effectiveness of the airbag.

Since the airbag fire-times were collected form either the frontal rigid barrier impacts or frontal offset impacts, the estimates from our model for the number of people on the module at the time airbag fires may not represent the numbers in the field, which include a significant number of car to car crashes. It is possible that the real numbers could be between the results for rigid barrier impacts and the results for offset impacts. This is because the impact of a car to rigid barrier is a rare event and does not represent the real world and the impact of a car to offset deformable barrier could be softer than most car crashes. From the model, the estimated number of occupants on the module is zero for the rigid barrier impacts, therefore the real number may be lower than the one estimated from the offset impacts.

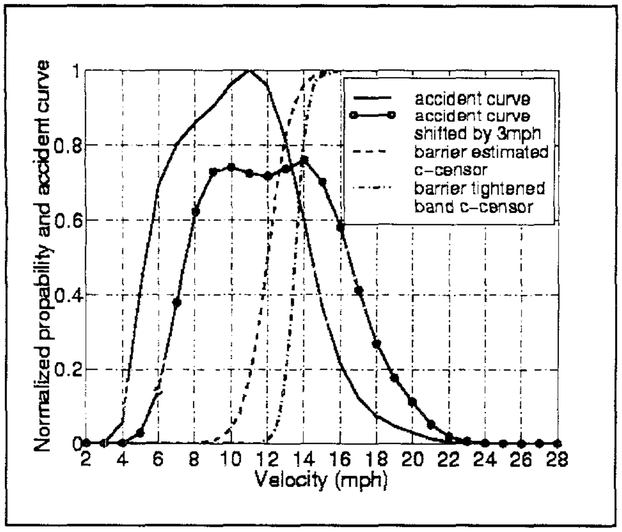

Figure 11: Probability with accident curve of the occupants on the module and two c-censors

The method of determining the distribution of the occupant's position at the time the airbag fires is straight forward. However, some processes used were not statistically rigorous. For example, the censoring of the data was not included in the statistical modeling. Instead, it was extracted out for the sake of constructing a calculus and ease of changing the censoring process.

The results and conclusions presented in this paper are obtained from a data based model constructed using both full frontal rigid barrier impacts and offset deformable barrier impacts, with the primary analysis done on the later. Although this process can lead to constructive insights, there are limitations to this approach and some of the assumptions may not be fully justifiable. For example, the lognormal function was chosen because among the functions evaluated it gave the best fit and it passed the Kolmogorov-Smirnov statistical test. In addition, the increased number of data points used to construct the model in this paper gave an even better fit for the 40 mph and 35 mph fire-times, but a worse fit for the 25 mph fire-times. However, we have been unable to identify the physical mechanisms that would imply a lognormal distribution. The choice of lognormal could disguise the relevant physics. Associated with the airbag firing initiation, the distribution could be more complex, such as bimodal.

Figure 12 shows a deployment rate of airbag fire-times for the 25 mph, 35 mph and 40 mph offset impacts. The deployment rate at time t_0 is defined as the probability that an airbag will deploy in the next millisecond after t_0 if it has not deployed before t_0. The deployment rate is estimated by counting how many airbags deployed between t_0 and t_1 and then dividing by how many were undeployed at t_0, giving us a percentage, and then dividing by t_1-t_0. Another way to visualize deployment rate is to imagine a large number of vehicles simultaneously suffering an offset collision at the same speed. The deployment rate at t_0 is the percentage of airbag deploying per millisecond at time t_0. The deployment rate is introduced here because an increasing deployment rate, such as observed for the 40 mph data indicates a lognormal distribution. For a lognormal distribution, it is expected that the deployment rate increases with time. However, no increase is observed in 25 mph and 35 mph data. Their deployment rate actually falls to zero for several milliseconds. It is to be hoped that when a large amount of new data become available, a more accurate deployment rate can be reached, and a better understanding of the statistical process can be developed. It should be noted that, there is no deviation for the airbag fire-time surface for the rigid frontal impacts by using a lognormal as a fitting function.

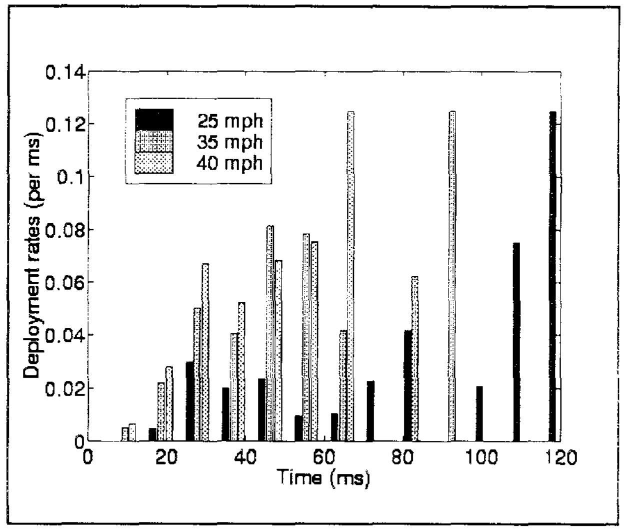

Figure 12: Deployment rates for 25 mph, 35 mph and 40 mph offset impacts

Another limitation is that the stability and the accuracy of the predictions from this data based model still depend on the fire-time data, the accuracy of NASS/CDS data and c-censor estimates. The extrapolating process may also affect the results. Therefore, this is still an on-going process. Improvements in the numerical procedure are still under development. In the future, if the results from the model no longer vary with the new data, the model can then be considered complete.

The c-censor as well as the airbag fire-time probability surface are not stationary in time or space. This is, in part, a result of the changing structure of the vehicles on the road as well as the changing nature of the highway structures. Even if a vehicle and it's sensor, once designed, stay the same there could still be significant changes in the c-censor and airbag fire-time probabilities for that vehicle. For example, although the c-censor is designed against a well defined set of tests, such as barrier impacts, crashes in the field are not predictable and they will change with the mix of cars, trucks and highway structures. A vehicle designed in one year may have a c-censor and airbag fire-time probability with certain characteristics in the field, but those characteristics will change over time as new vehicles of different designs become available. They will also change over the space if the vehicle is driven in different areas with an altered mix of vehicles and different highway structures.

CONCLUSION

This has been a limited preliminary study to determine the effect of probabilistic airbag fire-time on occupant position. A method for constructing probabilistic models, which calculates the probability of an occupant at a given position, has been developed. The models are a function of the initial seating position, crash severity, and airbag sensor nature, as well as occupant motion. The accuracy of the results is significantly dependent on the data used to construct the models and the numerical method to some degree. The two sets of data used in this study to construct the two different models were, rigid barrier and offset deformable barrier. Although these two models gave significantly different results in terms of absolute numbers, the trends observed were the same: airbag fire-time is probabilistic with inherent uncertainty. Although new data was used in the analysis, the conclusions are similar to the previous work [1]. The following conclusions are the result of analysis using the two models:

1. The model developed from the rigid barrier impacts indicates that it is unlikely for an occupant to contact the airbag module when the airbag fires.

2. The model developed from the offset deformable barrier indicates that it is possible for the occupant to contact the module as a result of late airbag firing.

3. Increasing the number of low velocity offset impacts (25 mph) did not significantly change the results.

4. The effect of changing "threshold velocity" is indeterminate because threshold is poorly defined. Airbag fire/no-fire probability distribution (c-censor) as a function of velocity is significantly more complicated than can be described by a single value.

5. The effect of increasing the c-censor velocity distribution for the airbag sensor is dependent on the number of crashes at a given velocity and the probability of firing for all velocities (characteristic of the c-censor).

   A. If the NASS/CDS velocity is accurate, then increasing c-censor velocity distribution will reduce the number of occupants in contact with the module when the airbag fires.

   B. If the NASS/CDS velocity is an underestimation, then increasing the c-censor velocity distribution may increase or decrease the number of occupants on the module. The amount of underestimation will affect the magnitude and direction of the change.

   C. The probability of fire/no-fire characteristics of a sensor is a significant factor in determining the effect of late fire on the number of occupants that may contact the module at the time of airbag initiation.

   D. The probability of fire/no-fire characteristics of a sensor is a significant factor in determining the effect of increasing the c-censor velocity distribution.

   E. Increasing the c-censor velocity distribution decreases the effectiveness of the airbag by increasing the number of late fires in those crashes in which the airbag fires.

6. The effect of tightening the band from c-censor velocity distribution may be useful in decreasing the number of occupants on the module without decreasing the effectiveness of the airbag.

REFERENCES

[1] Guy Nusholtz, Lan Xu, and Gregory Kostyniuk, "Estimation of Occupants Position from Probability Manifolds of Airbag Fire-times', SAE 980643, 1998

[2] Sheldon L. Stucki and Osvaldo Fessahaie, "Comparison of Measured Velocity Change in Frontal Crash Tests to NASS Computed Velocity Change",SAE 980649, 1998