A New Approach in Improving Traffic Accident Injury Prediction Accuracy

Chinmoy Pal 1)  Shigeru Hirayama 1)  Narahari Sangolla 2)  Jeyabharath Manoharan 2)  Vimalathithan Kulothungan 2)

1) NISSAN Motor Co. I-1 Aoyama, Morinosato, Atsugi, Kanagawa, Japan (E-mail: c-pal@mail.nissan.co.jp)
2) Renault Nissan Technology Business Center, Chennai, TN, India

Received on June, 19, 2017

ABSTRACT: This paper focused on the effect of intrusion magnitude and maximum deformation location in improving the accuracy of Injury Severity Prediction (ISP) for Advanced Automatic Crash Notification (AACN) system. This study used 545-passenger vehicles involved in Car-to-Car side impact data from NASS CDS (CY: 2004-2014). Variables mentioned in Kononen’s 2011 ISP algorithm are considered as base model. In addition to Kononen’s variables, magnitude of intrusion and maximum deformation location are added in the proposed model. As the location of maximum deformation moves away from the B pillar to end regions (front or back), the percentage of serious injury reduces drastically. Similar trend is verified in both accident analysis and FE numerical simulation results. Addition of intrusion magnitude and location of maximum deformation as additional injury predictors helped to improve the proposed model sensitivity, overall accuracy by 16%, 3.12% respectively without any change in specificity value.

KEY WORDS: Safety, AACN, Injury Severity Prediction Algorithm, Accident Analysis,[C1]

1. Introduction

Improving the accuracy of Injury Severity Predictions (ISP) algorithms for Advanced Automatic Crash Notification (AACN) system is an important task. Many researchers developed ISP algorithms from different crash predictors in the past. A new methodology is proposed in Figure 1. This study considered variables mentioned in Kononen’s ISP algorithm as “base model”. Kononen’s ISP algorithm variables along with intrusion magnitude, location of maximum deformation are considered as “proposed model”. Proposed model operates in two stages a) first stage (1, 2, 3, 4, 7): AACN system uses Kononen’s variables and predict injury severity and based on which Emergency Medical Services (EMS) will be dispatched and b) second stage (5 & 6, 7): EMS team will convey the deformation related information for more refined prediction of serious injury.

![Fig 1. Overview of Proposed AACN system](image-url)
2. Data and Methods

2.1 Approach

The base algorithm consists of seven important crash variables: Delta-V, Seatbelt usage (used or not used), Type of vehicle (Car, SUV, Pick up, Van), Number of events (Single or Multiple event), Principal Direction of Force (PDOF-front, left, right and rear), Age (>60 or <60) and Gender (Male or Female). In addition to the base model variables, the proposed model used intrusion, location information as additional injury predictors. However, the proposed model did not include vehicle type and gender variables as injury predictors because they are not significant variables (i.e., weak predictors) in identifying the serious injury cases as mentioned by Kononen’s 2011 ISP algorithm. Kononen’s ISP algorithm used PDOF as four directions (front, left, right and rear as reference) but proposed model is developed only for left side impacts as the intrusion magnitude and location of deformation plays an important role in causing the serious injuries to the drivers involved in side impact crashes especially at intersection. Injury severity score (ISS>15: serious, ISS<15: minor) considered as dependent variable and all the other variables considered as independent variables in logistic regression model (5)(6). To develop Injury Severity Prediction algorithms, Center for Decease Control (CDC) recommended certain guidelines (7). As shown in Table 1, different sets of variables are considered in five different models to develop the logistic regression equations. Five different models are chosen to test the accuracy level of injury severity algorithms. Variables mentioned in Kononen’s ISP algorithm are considered as base model (Model 1). Intrusion magnitude and location of maximum deformation information are added in proposed model (Model 5).

Table 1. Variables used in different logistic models

| Model 1 (base)  | Model 2                | Model 3                          | Model 4                   | Model 5 (proposed) |
|------------------|------------------------|----------------------------------|---------------------------|--------------------|
| Delta-V, belt use, no. of events, age, gender | Delta-V, belt use, no. of events, age, intrusion | Delta-V, belt use, no. of events, age, location of max. deformation | Delta-V, belt use, no. of events, age, internal intrusion magnitude, location of max. deformation |

2.2 Data

This study used 11 years (CY 2004-2014) of crash data from National Automotive Sampling System Crashworthiness Data System (8) (NASS-CDS). Different criteria to filter input data are summarized in Table 2. Crashes with primary general area of damage as top or bottom are omitted from this study. In total, 545 accident cases are extracted from CY 2004-2014, to perform the accident analysis and logistic regression analysis. Six Collision Deformation Codes (CDC) and some typical examples of deformation pattern are shown in Figure 2 and Figure 3, respectively.

Table 2. List of criteria for input dataset

| General Area Damage = Left |
| Direction of Force = 8, 9, 10 |
| Impact Location=F, P, Y, B, D, Z |
| Body Type: PV (1-9,17) |
| Model Year>=2000 |
| Driver Role=1 (Seat Position=11) |
| Age16+ |
| V2V OBJCTD<=30 |
| Towed Away Vehicles |
| No Ejection |
| No Rollover |
| No Fire Occurrence |
| Excluded AIS7 injury |

Fig 2. Collision Deformation Code

Fig 3. Deformation pattern in six CDC locations
3. Results

The following sections explain the results of accident analysis as well as FE numerical simulation results and highlights the effect of intrusion magnitude and location of maximum deformation on the performance of ISP algorithm related to AACN system.

3.1 Accident Analysis Results

3.1.1 Significance of impact location

All the six deformations zones divided into two parts as center (deformation zones: P, Y, Z, D) and end regions (deformation zones: F, B). Then the percentage of serious injuries is calculated in two regions as shown in Figure 4. It showed that a higher number of serious injuries are occurring at center compared to end regions. This shows the importance of location of impact to identify serious injuries.

Fig 4. Variation of serious injury percentage at center and two end regions (front and rear)

At first, to determine the relation between serious injury and location of impact, a univariate logistic regression test is performed as shown in Table 3. It showed that the impact location, when center is compared to end regions, is a significant (\( p < 0.002 \)) parameter in predicting the serious injury. Odds-ratio 6.08 indicates the chance of having serious injuries is 6 times more with impact at center region than at the ends.

Table 3. Univariate logistic regression model

| Serious injury prediction | Value | Wald Chi-Square | \( ^{*} p > \text{Chi}^{2} \) | Odds-ratio |
|---------------------------|-------|-----------------|-----------------------------|------------|
| Constant                  | -3.81 | 43.96           | < 0.0001                   |            |
| Impact @ end (reference)  | 0.000 |                |                            |            |
| Impact @ centre           | 1.80  | 9.19            | 0.002                      | 6.08       |

As the serious injury is varying with respect to location of impact, location of maximum deformation from B pillar information are collected manually from all the 545 vehicle’s pictures that are documented in NASS CDS database. The percentage of serious injury are plotted with respect to location of external maximum deformation value as shown in Figure 5. B pillar location is considered as reference position. It showed that the percentage of serious injury is more near the B pillar and it starts reducing as the location of maximum deformation moves away from B pillar and shifts towards the end regions, either front or back end. Hence, the location of maximum deformation can be a good predictor of injury in Injury Severity Prediction (ISP) algorithms. The magnitude of average intrusion values plotted against the location of maximum deformation as shown in Figure 6. It showed that the average values of intrusion are increasing when the location of maximum deformation moves away from B pillar to end regions. The percentage of serious injury is high even though the average intrusion value is low near the B pillar.

Fig 5. Variation of serious injury percentage (ISS>15) with respect to location of maximum deformation

Fig 6. Variation of average intrusion value with respect to location of maximum deformation

3.1.2 Significance of compartment intrusion magnitude

The percentage of serious injury plotted with respect to intrusion magnitude (cm) are shown in Figure 7. As the intrusion magnitude increases, the percentage of serious injury increases. Therefore, serious injury is directly proportional to intrusion magnitude. The percentage of serious injury is crossing 20% when the intrusion magnitude is in the range of 16 to 30 cm. Hence, intrusion magnitude (beyond 30cm) can be a good predictor of serious injury in Injury Severity Prediction (ISP) algorithm.

Fig 7. Variation of serious injury (ISS>15) percentage with respect to compartment intrusion magnitude
Hence, both the variables, intrusion magnitude and location of maximum deformation are very important to consider in identifying the injury severity in side impact crashes.

Please note that in real world accident, there are lot variables or factors (delta-V, mass of the striking and struck vehicles, occupant size, BMI, location and angle of impact, seating position, gender, type of vehicle, etc.) affect the response of injury outcome of the occupant in a very complex manner. In that respect, each accident is unique and no two accidents are exactly similar. Hence, to verify the effect of location of impact, one has to verify properly the degree of sensitivity of location of impact in a more constrained and controlled loading condition. However, it can be easily verified out by FE simulation. At the same time, all the vehicles, which are running on the road, are designed and evaluated in NCAP and IIHS test conditions to ensure certain level of occupant safety. In the following section, the trend of the sensitivity of impact location of certain vehicles in IIHS and SINCAP conditions is discussed briefly. Again, these safety performance evaluation procedures are based on PMHS tests and accident statistics of car-to-car collisions. Hence, the calculated sensitivity of occupant injury in car to barrier FE simulations will properly reflect the trend of occupant injury variations in car-to-car accidents in real world in a similar crash condition.

3.2 FE Numerical Simulation Results
In this section, the trend of injury sensitivity is verified with FE numerical analysis by changing the barrier to car impact conditions as shown in Figure 8. A series of FE simulations were performed by varying the impact location and the angle of the impacting barrier at regular intervals on both the sides of vehicle (front and back ends) using AM50 and AF05 side impact dummies. However, only three tests configuration are shown in Figure 8 (base, front-end & back-end).

![Fig 8. FE simulation test configurations](image)

The injury variations in different body regions (chest, abdomen, and pelvis) are shown in Figure 9, as the location of barrier changes. The injury decreases in all three-body regions as the impact of barrier edge moves away from the driver seating position to end regions as shown in Figure 8.

![Fig 9. Variation of injury in three body regions: thorax, abdomen, and pelvis](image)

FE simulation results also indicated similar trend as accident analysis. Changes in injury reduction were also observed when the angle of impact edge is varied from 8-o’clock to 10-o’clock as indicated in the Figure 2 of section 2.2. However, they are not mentioned here due to limitation of space. Figure 9 shows the general tendency of number of simulations carried out with different vehicles. Due to lack of space, individual simulation results are not described here.

3.3 Logistic Regression Results
Significance of intrusion magnitude and location of deformation by logistic regression test results are discussed in this section.

The whole dataset consists of 453 minor (83%) and 92 serious (17%) cases. Using Injury Severity Score (ISS) as a dependent variable, logistic regression coefficients of base and proposed models are developed. Table 4 summarizes the base model logistic regression equation. It showed that the variables delta-V, age>=60 and multiple events are strong predictors (significance p<0.05) of injury prediction, whereas the belt usage and gender are weak predictors (not significant p>0.05).

| Base Feature | Value  | Wald Chi-Square | Pr. > Chi² | Odds Ratio |
|--------------|--------|-----------------|------------|------------|
| Intercept    | -12.36 | 44.62           | < 0.0001   | 3.055      |
| Delta-V      | 2.851  | 30.91           | < 0.0001   | 17.304     |
| Age Binary   | 2.413  | 28.94           | < 0.0001   | 11.163     |
| Belt usage   | -0.050 | 0.007           | 0.936      | 0.951      |
| Events       | 1.560  | 12.79           | < 0.0001   | 4.710      |
| Gender Binary | 0.518 | 1.386           | 0.239      | 1.679      |

Table 5 summarizes the proposed model logistic regression coefficients. It showed that the variables delta-V, age>=60, multiple events, intrusion magnitude (>30cm), location of maximum deformation (>15cm to 10cm) are strong predictors (significance p<0.05) of injury prediction, whereas the belt usage parameter is a weak predictor (significance p>0.05).

Table 6 summarizes the prediction results of five models for comparison. Out of total 545 cases of base model, 94 cases were predicted as wrong prediction (Model overall accuracy estimated as 82.75%, with sensitivity of 46.74% and specificity of 90.07%). As shown in base model logistic regression equation, gender is not a significant predictor as described before. Hence, gender removed as injury predictor in all other remaining models (Model 2 to Model 5). Exclusion of gender from the base model shows small improvement in model performance. Overall accuracy of model increased from 82.75% to 83.49%. Model 3 shows the inclusion of intrusion magnitude to Model 2 as binary variable (<30cm, ≥ 30cm) and predicts only 81 cases as false prediction.

Table 4. Base model logistic regression model

Table 5. Proposed model logistic regression coefficients

Table 6. Prediction results of five models for comparison
Table 5. Proposed model logistic regression model

| Proposed Characteristic | Value | Wald Chi-Square | Pr > Chi² | Odds Ratio | Remarks |
|-------------------------|-------|-----------------|-----------|------------|---------|
| Intercept               | -14.797 | 45.792          | < 0.0001 |            | Significant |
| Ln (Delta-V)            | 2.786  | 26.935          | < 0.0001 | 16.216     | Significant |
| Age_Binary-0 (age<60)   | 2.480  | 25.762          | < 0.0001 | 11.947     | Significant |
| Belt usage_Binary-0 (belt used) | -0.229 | 0.126 | 0.722 | 0.795 | Not Significant |
| Location of deformation | 2.591  | 7.689           | < 0.0001 | 13.346     | Significant |

4. Discussion

Addition of intrusion magnitude and location of maximum deformation as injury predictors helped to improve the overall accuracy of model. However, proposed system can work only if intrusion magnitude and location of deformation information are available immediately after the crash. The first responders at crash scene has the opportunity to take the pictures of vehicle deformation patterns and quickly send the information back to Public Safety Answering Point (PSAP). Daniel V.M. et al. 2015 already developed a smart phone application, which transmits photographs of vehicle crash related information to trauma centers in advance of occupant arrival. That will help Emergency Medical Services in hospital to prepare well for treating a seriously injured occupant effectively. NASS CDS has been collecting information about intrusion magnitude but does not record direct information about location of maximum deformation from B pillar. Location of maximum deformation estimated manually by analyzing each individual vehicle’s deformation patterns, which are available in NASS CDS website. If NASS CDS provides information about location of maximum deformation with respect occupant seating position, there will be more scope of research in this field. Similar studies can be possible for other crash modes also.

4.1 Testing the accuracy of proposed model

Table 7 shows the prediction results of Model 2 (gender removed) and the corresponding ISS v/s ISP distribution is plotted in Figure 10. Based on Model 2 Stage-I algorithm, most of the predicted serious cases (90) will be carried to Grade-I hospital with the help of Emergency Medical Services (EMS) for better treatment of serious injured occupant. Out of 90 cases, 44 minor cases are predicted as serious (false prediction) and 46 serious cases predicted as serious (correct prediction). There is no concern with the 46 cases as they are predicted correctly as serious. However, there is opportunity to correct those 44 minor cases, which are predicted as serious. Most of those 44 cases occupants do not need to be carried to Grade-I hospital because they are actually not serious. Considering those 44 cases as a reference, results of refined prediction with proposed model 5 are shown in Table 8.
Table 7. Prediction results of Model 2

| N=545 | Stage-I Prediction |
|-------|--------------------|
|       | Actual             |                  |
|       | Minor 453          |                 |
|       | as Minor 409       | 90 cases EMU     |
|       | Serious 92         | as Serious 44    |
|       | as Minor 46        | 24               |

Using the proposed Stage-II refined prediction, 20 cases are predicted as minor when compared with Model 2 prediction and its ISS v/s ISP scattered distribution are plotted in Figure 11. Within those 20 cases, it is found that there are seven cases far away (ISP<0.14) from predefined 0.2 decision line. This shows the efficacy of the proposed model in predicting minor cases as minor. This may be helpful in improving the overall efficiency of an AACN system.

Table 8. Prediction results of proposed model

| Stage-II Prediction (5,6) |
|---------------------------|
| From Model 2 prediction   | Minor as Serious 44 cases | as Minor 24 | 20 cases identified as minor |

Using the proposed Stage-II refined prediction, 20 cases are predicted as minor when compared with Model 2 prediction and its ISS v/s ISP scattered distribution are plotted in Figure 11. Within those 20 cases, it is found that there are seven cases far away (ISP<0.14) from predefined 0.2 decision line. This shows the efficacy of the proposed model in predicting minor cases as minor. This may be helpful in improving the overall efficiency of an AACN system.

4.2 Limitation

Please note that all the above-mentioned results are verified for only PV struck vehicles in C2C intersection accidents but not for other vehicle types. However, considering all possible accident scenarios, further verifications are necessary using various combinations of C2C experiments using different dummies and types of vehicles in order to make any generalized statement as stated above.

5. Summary and Conclusion

This paper discussed the effect of intrusion magnitude and location of maximum deformation in improving the accuracy of injury severity prediction for Advanced Automatic Crash Notification (AACN) system using 545-passenger vehicles involved in Car-to-Car side impact data from NASS CDS (CY: 2004-2014). The following specific conclusions drawn from this study:

- As the intrusion magnitude increases, the percentage of serious injury also increases. Hence, intrusion magnitude is a key variable as an injury predictor.
- As the location of maximum deformation moves away from the B pillar to end regions (front or back), the percentage of serious injury reduces drastically and verified the trend with both accident analysis and FE numerical simulation results. Even low average intrusion near the B pillar region can lead to higher serious injury. Hence, both intrusion magnitude and location of deformation together can be considered as key predictors of injury.
- The proposed ISP model performs well when compared with the base model. The sensitivity and overall accuracy of model are improved by 16% and 3.12% respectively without any change in specificity. Hence, inclusion of intrusion magnitude and location of maximum deformation as injury predictors along with the Kononen’s base variables, can definitely improve the overall accuracy of AACN ISP algorithm. Similar analysis is possible for other crash modes also in future.

References

(1) Kononen, D. W., Stewart C. Wang, et al., 2011, “Identification and validation of a logistic regression model for predicting serious injuries associated with motor vehicle crashes”, Accident Analysis and Prevention, Vol. 43, pp:112–122(2011).
(2) Babouth, G., Diggles, K.H., Bedewi, N.E., Kuznetsov, A., Augustin, J.S., Perdeck, E., 2004, “Development of URGENCY 2.1 for the prediction of crash injury severity”. Topics in Emergency Medicine, Vol. 26, pp: 157–165(2004).
(3) Ruben B, et.al, 2015, “On scene injury severity prediction (OSISP) algorithm for car occupants”. Accident Analysis and Prevention, Vol.81, pp: 211-217 (2015).
(4) Daniel V.M., Robert P.K., Christopher T.B., Karisa K. H., Michele A.L., 2015, “Utilization of crash scene photos of vehicle damage and intrusion to improve trauma care preparedness”. Traffic Injury Prevention. 2015. ESV paper number 15-0167.
(5) David G. Kleinbaum Mitchel Klein, Logistic Regression, A Self Learning Text, Third Edition. ISBN: 978-1-4419-1741-6 (2010)
(6) XLSTAT User’s Guide, version, 2015.1.1(2015).
(7) CDC Expert Panel Recommendations: Advanced Automatic Collision Notification and Triage of the Injured Patient, Vol.1, pp 1-20, (2008); http://stacks.cdc.gov/view/cdc/5304/cdc_5304_DS1.pdf (accessed 2014.12.1).

(8) National Highway Traffic Safety Administration (NHTSA), National Automotive Sampling System (NASS) Crashworthiness Data System Analytical User’s Manual 2009, National Center for Statistics and Analysis, U.S. Dept. of Transportation, Washington, DC, Vol.1, pp:1-155, (2009); https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/NASS09 (accessed 2015.12.1).

Abbreviation

| Abbreviation | Description                                      |
|--------------|--------------------------------------------------|
| AACN         | Advanced Automatic Crash Notification            |
| AUC          | Area Under the Curve                             |
| C2C          | Car to Car                                       |
| EMS          | Emergency Medical Services                        |
| ISP          | Injury Severity Prediction                        |
| ISS          | Injury Severity Score                             |
| NASS-CDS     | National Automotive Sampling System Crashworthiness Data System |
| PV           | Passenger Vehicle                                |
| PSAP         | Public Safety Answering Point                    |
| PDOF         | Principal Direction of Force                     |
| SUV          | Sport Utility Vehicle                            |