SECOND GENERATION AACN INJURY SEVERITY PREDICTION ALGORITHM: DEVELOPMENT AND REAL-WORLD VALIDATION

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ABSTRACT

Advanced automatic collision notification (AACN) based injury severity prediction (ISP) has great potential to improve post-crash care. The national Expert Panel for Field Triage set 20% risk of Injury Severity Score (ISS) 15+ injury as the threshold for urgent transport to a trauma center. Earlier, we published an Injury Severity Prediction algorithm (ISP v1) that was developed using data from the National Automotive Sampling System Crashworthiness Data System (NASS_CDS) for the calendar years 1999-2008. In a field trial published at ESV 2015, this ISP algorithm version 1 demonstrated better than predicted sensitivity to detect seriously injured (ISS15+) crash occupants. In the current study, we sought to a) update the ISP algorithm using more current NASS-CDS data, b) improve predictive accuracy by refining the granularity of the input data, and c) validate the ability of this updated algorithm (ISP v2) using real-world crash cases involving GM vehicles equipped with OnStar.

NASS-CDS data (1999-2013) was used to develop a functional logistic regression model to predict the probability that a crash-involved vehicle would contain one or more occupants with ISS 15+ injuries in planar, non-rollover crash events involving Model Year 2000 and newer cars, light trucks, and vans. Two of the parameters used in the original ISP algorithm were modified (principal direction of force [PDOF], older occupant age) and a new parameter was created and involved the presence of a right-sided passenger. This study was approved by the IRB of the Michigan Department of Health and Human Services (formerly the Michigan Department of Community Health). The initial 924 occupants in 836 crashes published in the 2015 study were again opened for review and injury severity predictions from the updated algorithm were compared to the observed injury outcomes.

The updated ISP v2, which employs the functional data analysis technique to model the effect of PDOF to ISS 15+ injury as a continuous cyclic function, showed an improved predictive performance (AUC 0.872, AIC 2370) over the original ISP v1 (AUC 0.865, AIC 2377) that used only 4 crash directions. The original elderly age cutoff of 55 performed better than an age cutoff of 60, so age ≥55 was retained as a parameter in ISP v2. Using field data for validation, the updated ISP algorithm had significantly improved sensitivity for detecting seriously injured (ISS 15+) occupants (72.7% vs. 63.4%) with minimal changes in specificity (93% vs 94%). The AUROC for ISP v2 was 0.946, an improvement over the AUROC for ISP v1 (AUROC 0.932).

This study confirms under real world field conditions that occupant injury severity can be predicted using vehicle telemetry data. The updated ISP v2 algorithm's ability to predict a 20% or greater risk of severe (ISS15+) injury confirms ISP's utility for the field triage of crash subjects.

INTRODUCTION

According to the Centers for Disease Control (CDC), in 2014 2,412,109 occupants were injured and 33,736 occupants were killed in motor vehicle crashes in the US alone. [4] Numbers are higher across the globe, with the World Health Organization (WHO) stating up to 50 million people are injured and over 1.2 million people killed in MVCs.[5] It appears there is still much work to be done to decrease these numbers.

Minimizing the time between injury and treatment is vitally important to reduce morbidity and mortality. First responders must arrive at the scene quickly, with appropriate equipment, to treat, triage, and transport occupants to the appropriate medical center for further care. There is a 25% reduction in mortality if occupants arrived at a Level I Trauma center versus a non-Trauma center. [6]

The CDC's National Expert Panel concluded that AACN showed promise in improving outcomes to severely injured crash patients by:

- Predicting the likelihood of serious injury in vehicle occupants
- Decreasing response times by pre-hospital care providers
- Assisting with field triage destination and transportation decisions
- Decreasing time to definite trauma care
- Decreasing death and disability from MVCs

This panel recommended that pilot studies be conducted using vehicle telemetry data including:

- Delta V (crash severity)
- PDOF
- Seatbelt usage
- Crashes with multiple impacts
- Vehicle type

Additionally, the panel recommended that voice communication be established to determine the presence of injuries and also to collect additional information that might affect injury risk. It endorsed calculating the injury risk with all available data and that if the occupant is at 20% or greater risk of ISS 15+ injury, the relevant Public Safety Answering Point (PSAP) should be notified that the occupant meets the Field Triage Decision Scheme's Step 3 criterion for "vehicle telemetry consistent with high risk of injury" and appropriate resources dispatched. [1]

With these recommendations in mind, the first ISP algorithm was developed using a logistic regression model of national representative crash data (NASS-CDS, calendar years 1999-2008). [2] This dataset provided a model sensitivity of 40% and specificity was 98% using an injury probability cutoff of 20% risk of ISS >15. In a field trial published at ESV 2015, this ISP algorithm version 1 demonstrated better than predicted sensitivity to detect seriously injured (ISS15+) crash occupants. [3] In a field trial published at ESV 2015, this ISP algorithm version 1 demonstrated better than predicted sensitivity to detect seriously injured (ISS 15+) crash occupants. [3] In the current study, we sought to a) update the ISP algorithm using more current NASS-CDS data, b) improve predictive accuracy by refining the granularity of the input data, and c) validate the ability of this updated algorithm (ISP v2) using real-world crash cases involving GM vehicles equipped with OnStar.

METHODS

NASS-CDS data (1999-2013) was used to develop a functional logistic regression model to predict the probability that a crash-involved vehicle would contain one or more occupants with ISS15+ injuries in planar, non-rollover crash events involving Model Year 2000 and newer cars, light trucks, and vans. Unchanged model input parameters from ISP v1 included: change in velocity (Delta-V), multiple vs. single impacts, belt use, presence of a female occupant, presence of an older occupant (≥55 years of age), and vehicle type (car, pickup truck, van, and sport utility). Two of the parameters were modified to address opportunities noted in results from the field trial of ISP v1.

Modified input parameters included: PDOF as a continuous input, ranging from 0 to 360 degrees (instead of 4 crash directions: front, left, right, and rear) and the presence of an older occupant (≥55 years old vs. ≥60 years old). To investigate PDOF as the actual degrees rather than direction categorization, we used a functional data analysis approach and modelled the logarithm of the relative odds of PDOF on injury risk as a continuous cyclic function ranging from 0 to 360 degree. The function was modelled as cyclic basis splines with 10 degrees of freedom.

There was discussion regarding the original age cut off of >55 years. We divided occupants with a series of different age cutoffs, ranging from 40 to 70 years.

For each age cutoff, we compared the risk of having an ISS 15+ injury between two groups and calculated p-values. Figure 1 shows the logarithm of p values versus age cutoffs. P-values steadily decrease until approximately the age of 60. In developing ISP v2, we investigated whether choosing an older age cutoff would improve the prediction accuracy.

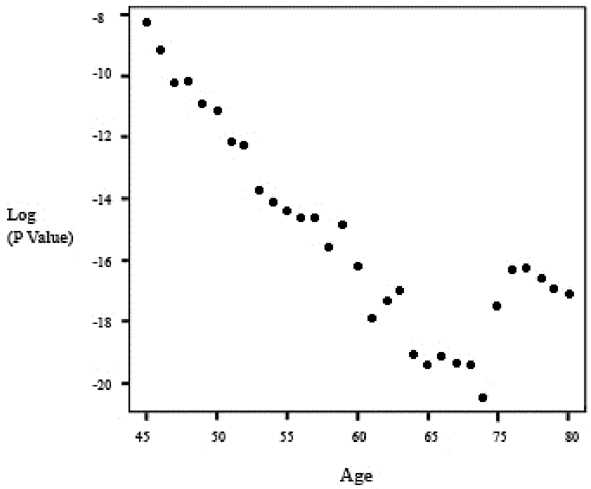


Figure 1: **Age cutoffs and logarithm of p values.**

A new input parameter included presence of a right-sided passenger and its interaction with PDOF. When a right-side passenger is present, another functional curve of PDOF was added to the model. This represents the additive injury risk due to the right-side passenger. The logarithm of relative odds of PDOF for this injury risk was modelled as cyclic basis splines with 5 degrees of freedom.

Finally, in developing ISP v2, we employed a forward/backward selection procedure. Starting from the null model, in each step, we added or removed one variable to minimize Akaike Information Criterion (AIC). The procedure stops when AIC cannot be improved and the final model is then reported.

924 occupants in 836 crash events involving vehicles equipped with AACN capabilities in the state of Michigan were identified from the OnStar records. The injury status of all occupants in the case vehicles was determined. The updated algorithm (ISP v2) was used to calculate the predicted risk of injury based on transmitted telemetry data and this prediction was compared to the observed injury outcome.

RESULTS

We compared the predicted versus observed injuries for four different models:

- ISP v1 refitted with NASS-CDS data through year 2013
- ISP v1 refitted, but using the age cutoff as 60
- ISP v2 with inputs as logarithm of Delta V, 10 cyclic basis splines for PDOF, 5 cyclic basis splines for PDOF when right-side passenger is present, belt status, vehicle body type, if multiple events, if age is equal to or older than 55, gender
- Same as ISP v2, but use if age is equal to or older than 60

Table 1.
Coefficients

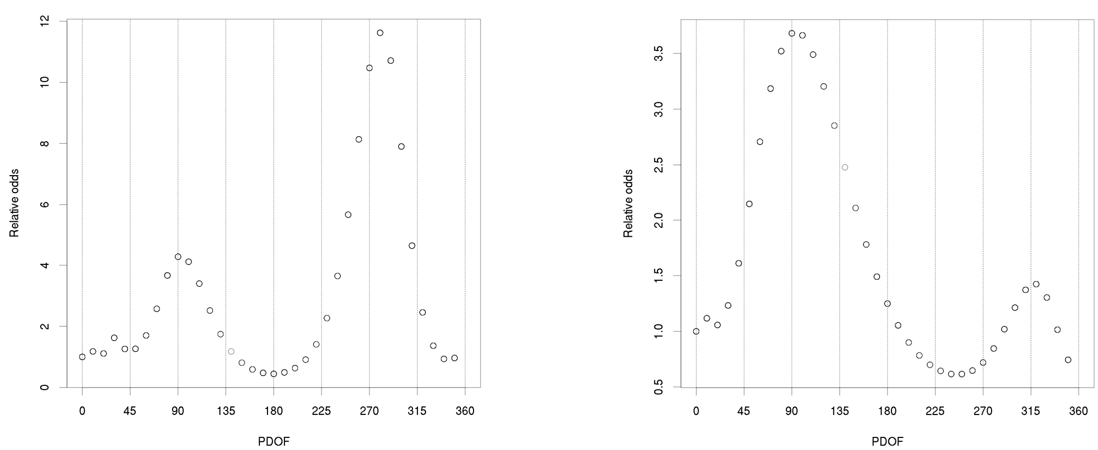
	Est	SE	P values
Intercept	-11.715	3.196	<0.001
ln delta-V (mph)	4.040	0.248	<0.001
If all occupants belted	-1.472	0.234	<0.001
If at least one occupant > 55	1.179	0.141	<0.001
If a multiple event	0.458	0.144	0.001
If at least one female	0.231	0.119	0.052
PDOF (splines with df = 10)	-5.524	4.951	0.265
main effect	-2.946	2.743	0.283
	-4.515	3.706	0.223
	-0.583	3.202	0.856
	-8.505	3.273	0.009
	1.303	3.735	0.727
	-4.070	3.287	0.216
	-4.156	3.722	0.264
	-3.649	3.055	0.232
	-3.986	3.490	0.253
PDOF (splines with df = 5) when there is also a RFP	3.739	1.001	<0.001
	-2.334	1.270	0.066
	1.338	0.660	0.043
	-0.295	0.471	0.531
	0.572	0.441	0.195

Table 2.
The performance of the four statistical models using NASS data.

	AIC	AUC
ISP v1	2377.34	0.865
ISP v1 (Age cutoff: 60)	2387.72	0.864
ISP v2	2370.40	0.872
ISP v2 (Age cutoff: 60)	2384.75	0.871

Note that smaller AIC results in better fit of data, while a larger AUC indicates better predictive ability of the models. Consistently, seen from both AIC and AUC, ISP v2 performs better than ISP v1. Choosing age cutoff as 60, identified through univariate analysis, actually leads to worse results in the multivariate analysis. We therefore chose model 3 above (i.e. ISP v2 with age cutoff of 55) as the final model.

The functional curves of relative odds of severe injury for the full range of PDOF are presented in Figure 2. We chose 0 degree PDOF as the reference point, and plotted the relative odds of PDOF for drivers (left) and right-side passengers (right). For drivers, the relative odds increased to 4 as PDOF increased to 90 degrees. The increase of odds seems not linear and more dramatic after 45 degrees. This somewhat suggests a smaller window for side-impact injury risk. The relative odds then decreased to ~ 0.5 when PDOF was close to 180 degrees. From there, the relative odds increased to about 12 when PDOF was close to 270 and dropped back to 1 when PDOF reached 360.



Driver Right-side Passenger

When there is a right-side passenger, the additive relative odds of ISS 15+ injury peaked at 3.8 when PDOF was near 90 degrees. There is a smaller peak of relative odds at 1.5 when the impact came from the left side. Interestingly, the PDOF corresponding to this peak is not at 270 degrees, but closer to 315 degrees, which is a left, frontal impact.

We validated the new developed model with the OnStar data used in our 2015 ESV study. Our OnStar dataset has 924 occupants in total, and represents a slightly different population than NASS-CDS from which the predictive model was developed. The median age in OnStar is 41 years old. 57% are female. 21% are right-side passengers. Only 1.2% of occupants have ISS 15+ injury. We included rear seat passengers in this study of occupant outcomes (rear seat passengers were not considered when developing the predictive model).

Figure 2: **Functional curves of relative odds of severe injury for the full range of PDOF.**

The updated ISP v2, which employs the functional data analysis technique to model the effect of PDOF to ISS 15+ injury as a continuous cyclic function, showed an improved predictive performance (AUC 0.872, AIC 2370) over the original ISP v1 (AUC 0.865, AIC 2377) that used only 4 crash directions. The original elderly age cutoff of 55 performed better than an age cutoff of 60, so age ≥55 was retained as a parameter in ISP v2.

Using field data for validation, the updated ISP algorithm had significantly improved sensitivity for detecting seriously injured (ISS 15+) occupants (72.7% vs. 63.4%) with minimal changes in specificity (93% vs 94%). The AUROC for ISP v2 was 0.946, an improvement over the AUROC for ISP v1 (AUROC 0.932).

Table 3:
ISP v1 Sensitivity and Specificity

	-	+	
-	858	55	Sensitivity: 63.4% Specificity: 94%
+	4	7	

Table 4:
ISP v2 Sensitivity and Specificity

	-	+	
-	852	61	Sensitivity: 72.7% Specificity: 93%
+	3	8	

DISCUSSION

The Injury Severity Prediction algorithm was updated using current NASS-CDS data. This updated algorithm (ISP v2) with PDOF included as a continuous input rather than four discrete crash directions shows significantly improved sensitivity to detect seriously injured (ISS 15+) occupants, whether drivers or right-sided passengers.

The field performance of ISP v2 utilizing the OnStar dataset showed 72.7% sensitivity and 93% specificity. Sensitivity is defined as the probability that a test result will be positive (ISP≥0.2) when the condition (ISS 15+) is present. The observed sensitivity performance was better than the 40% performance that ISP v1 achieved when applied to the NASS-CDS dataset and better than the 63.4% performance that ISP v1 achieved when applied to the same field cases. As previously stated, the more consistent and accurate measurements of crash severity, more accurate determination of restraint use, and more consistent vehicle safety performance due to the vehicles being from a single manufacturer and being newer models may play a part in the better performance of the algorithm.

The specificity performance of the ISP in this study was 93%. Specificity is defined as the probability that a test result will be negative (ISP<0.2) when the condition (ISS>15) is not present. The observed specificity performance was less than the 98% performance that the algorithm achieved when applied to the NASS-CDS dataset and slightly less than ISP v1 specificity of 94% when applied to the field cases. While the overall number of cases studied is relatively small, there were fewer ISS>15 injured cases observed than would have been expected based on the number of cases, configuration and crash-severity mix of the crashes included in this study. This trend might be the result of continuously improving vehicle safety performance in the study fleet versus the NASS-CDS fleet used to calibrate the algorithm. The average age of the study fleet was younger than the average age of the vehicles in NASS-CDS. [3]

ISP v1 was developed from NASS-CDS data and defined crash direction into only four categories (front, left, right, and rear). Real world crashes cannot always fit into these groups and frequently fall into offset or narrow configurations that may impact injury risk. Right side and oblique impact crashes appear to be underweighted in ISP v1. In the 2015 field trial, observed injuries of right sided occupants suggested that it could be beneficial to adjust the right side impact coefficients to reflect a higher risk of severe injury if there is a right sided occupant in place during the crash.

In the current study, we modified the ISP algorithm to utilize crash PDOF as the actual degrees rather than 4 simple direction categories. We used a functional data analysis approach and modelled the logarithm of the relative odds of PDOF on injury risk as a continuous cyclic function ranging from 0 to 360 degree. The function was modelled as cyclic basis splines with 10 degrees of freedom. A new input parameter included presence of a right-sided passenger and its interaction with PDOF. When a right-side passenger is present, another functional curve of PDOF was added to the model. This represents the additive injury risk due to the right-side passenger. The logarithm of relative odds of PDOF for this injury risk was modelled as cyclic basis splines with 5 degrees of freedom. Examination of the OnStar cases used for validation showed improved injury prediction of right-sided crashes.

The theory that the ISP could be better improved with more granular age parameters rather than a single threshold of age 55 proved to be false. We divided occupants with a series of different age cutoffs, ranging from 40 - 70 years. For each age cutoff, we compared the risk of having an ISS 15+ injury between two groups. Choosing the age cutoff as 60 actually led to worse results in the multivariate analysis.

While it is well known that the increased crash injury risk accelerates with advancing age rather than plateauing, [6-9], in this analysis a cutoff of age 55 resulted in a better fit and better predictive ability for the algorithm. The Sensing and Diagnostic Module (SDM) does not have the capability to capture age data. When the telematics provider contacts the occupants in the crashed vehicle, they ask questions about who is in the vehicle. In this way, they can obtain age to send to the PSAPs. These results confirm the importance of age in injury risk calculation and highlight the importance of collecting this data.

Finally, in developing ISP v2, we employed a forward/backward selection procedure. Starting from the null model, in each step, we added or removed one variable to minimize Akaike Information Criterion (AIC). The procedure stops when AIC cannot be improved and the final model is then reported. We believe this to be a more consistent approach that can be used for future ISP iterations.

CONCLUSION

As with ISP v1 and the subsequent field trial, this study confirms under real world field conditions that occupant injury severity can be predicted using vehicle telemetry data. The updated ISP v2 algorithm's ability to predict a 20% or greater risk of severe (ISS 15+) injury confirms ISP's utility for the field triage of crash subjects.

The level of sensitivity for severe injury achieved by ISP v2 increased to a remarkable 72.7 achieved with only data or communication transmitted from the vehicle and before dispatch of EMS to the scene. Since the consequence of missing a severe injury is immediately life-threatening, sensitivity receives the highest priority in trauma care. The longstanding Field Decision Scheme has been used as the basis for triage protocols in state and local emergency medical systems (EMS) across the United States for many decades. The combined sensitivity of the first two steps (Physiologic and Anatomic) of the Decision Scheme has consistently remained ~ 40-50% with field data collected by first responders. [12-15]

Newer crash sensors may also support further improvements in the performance of the ISP algorithm. As the SDM systems change and more detailed telemetry data collection is possible, ICAM anticipates improvements in risk prediction. The fleet is in constant flux with new safety systems as well as enhanced SDMs. [16, 17]

Michigan, parts of the United States, and the world all have many rural areas where reports of crash events to public safety may be delayed, leading to slow response by EMS. [18, 19] These same areas are also characterized by long transport distances that will delay the transfer of the severely injured to medical facilities. Automatic collisions notification alone, without additional vehicle telemetry for injury prediction, can save significant lives [20]. Time is of the essence in these cases and getting these occupants to the proper medical destination capable of definitive trauma care is essential. Transmitted telemetry data from AACN can not only provide notification that a crash has occurred, it can also alert the local first responders as to what type and how severe of crash they are responding to – they will know what equipment to bring in order to best triage and treat the occupants. There is potential also to immediately initiate air transport and get them to the scene quickly as well.

The resources utilized in the emergency care of crash injuries place a significant burden on local communities, especially rural ones. Over triaging patients without severe injuries to trauma centers or other medical centers for unnecessary evaluation is expensive and wasteful. The recent changes to Step 3 (mechanism of injury) of the Field Triage Decision Scheme is estimated to provide yearly US savings of over $500 million in medical costs alone. [21] With widespread use of AACN, those savings can be multiplied. [3]

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